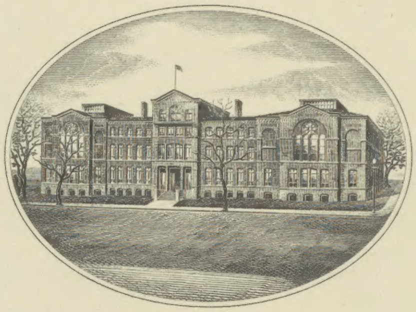
MAYO AERO MEDICAL UNIT

STUDIES IN AVIATION MEDICINE

Volume I

Preliminary Reports



2315

Stud. Aviat. M., Rochester

[illegible]

[illegible]

carried out with the assistance of the

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

acting for the

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

[illegible]

[illegible]

[illegible]

Cooperative Investigators: [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

MAYO AERO MEDICAL UNIT

STUDIES IN AVIATION MEDICINE

Carried out with the assistance of the

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

acting for the

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

COMMITTEE ON AVIATION MEDICINE

With the cooperation of the

UNITED STATES ARMY AIR FORCES, MATERIEL COMMAND, WRIGHT FIELD.

Responsible Investigators: Walter M. Boothby, E. J. Baldes and C. F. Code

aided by many associates.

In Six Volumes

These reports, originally in "restricted" classification,
have been declassified and all are now "open."

VOLUME I: PRELIMINARY STUDIES

Mayo Clinic and Mayo Foundation for
Medical Education and Research,
University of Minnesota

Rochester, Minnesota
1940 - 1945

COMMITTEE ON WAR MEDICINE, MAYO ASSOCIATES
representing the
MAYO CLINIC AND MAYO FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH
Dr. D.C. Balfour, Dr. C.W. Mayo*, Dr. R.D. Mussey, Dr. A.R. Barnes and Mr. H.J. Harwick

G 10-29-47

STAFF OF THE MAYO AERO MEDICAL UNIT

Responsible Investigators

High Altitude Laboratory: Walter M. Boothby, Chairman. Member of the Subcommittee on Oxygen and Anoxia of the Committee on Aviation Medicine, National Research Council.

Acceleration Laboratory:** E.J. Baldes, Vice Chairman. Member of the Subcommittee on Acceleration of the Committee on Aviation Medicine, National Research Council.
C.F. Code, Secretary. Member of the Subcommittee on Decompression Sickness of the Committee on Aviation Medicine, National Research Council.

Investigators

Staff of the Mayo Clinic and Mayo Foundation: (Full time) E.J. Baldes, J.B. Bateman, W.M. Boothby, A.H. Bulbulian, C.F. Code, H.F. Helmholz, Jr., E.H. Lambert, W.R. Lovelace, II and E.H. Wood. (Part time) J.D. Akerman,*** J. Berkson, H.B. Burchell, P.L. Cusick, H.E. Essex, G.A. Hallenbeck, W.W. Heyerdale, H.C. Hinshaw, J. Piccard,*** M.H. Power, C. Sheard, J.H. Tillisch, M.N. Walsh and M.M.D. Williams.

Fellows of the Mayo Foundation: R. Bratt, B.P. Cunningham, W.H. Dearing, E.W. Erickson, N.E. Erickson, J.H. Flinn, J.K. Keeley, J. Pratt, F.J. Robinson, R.F. Rushmer, G.F. Schmidt, H.C. Shands, H.A. Smedal, A.R. Sweeney, A. Uihlein, R. Wilder, Jr., J. Wilson and K.G. Wilson.

Officer assigned by the Air Transport Command of the Army Air Forces: K.R. Bailey, pilot

Officers assigned by Air Surgeon's Office: O.O. Benson, Jr., J.W. Brown, J.H. Bundy, D. Coats, E. Eagle, M.F. Green, J.R. Halbouty, R.B. Harding, J.P. Marbarger, M.M. Guest, O.C. Olson, C.M. Osborne, H. Parrack, N. Rakieten, J.A. Resch, H.A. Robinson, H.E. Savely, C.B. Taylor, L. Toth and J.W. Wilson.

Officers assigned by the Navy: W. Davidson and D.W. Gressley.

Officers sent by other governments: J.R. Delucchi, Argentina, and R.T. Prieto, Mexico.

Other investigators: M. Burcham, C.J. Clark, M.A. Crispin, R.E. Jones, G. Knowlton, H. Lamport, C.A. Lindbergh, C.A. Maaske, G.L. Maison, A. Reed and R.E. Sturm.

Technicians

High Altitude Laboratory: Henrietta Cranston, Lucille Cronin, Ruth Knutson, Eleanor Larson and Rita Schmelzer; Margaret Jackson (from Wright Field).

Acceleration Laboratory: L. Coffey, R. Engstrom, H. Haglund and A. Porter; Ruth Bingham, Velma Chapman, Marjorie Clark, Wanda Hampel and Marguerite Koelsch.

Secretaries

Evelyn Cassidy, Esther Fyrand, Marian Jenkins and Ethel Leitzen.

* Before going into military service.

** The major reports of the Acceleration Laboratory will be published shortly in the monograph entitled "The Effects of Acceleration and Their Amelioration," edited by the Subcommittee on Acceleration of the Committee on Aviation Medicine of the National Research Council.

*** From the Department of Aeronautical Engineering, University of Minnesota.

COMMITTEE ON WAR MEDICINE, MAYO ASSOCIATES
representing the
MAYO CLINIC AND MAYO FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH
Dr. D.C. Balfour, Dr. C.W. Mayo*, Dr. R.D. Mussey, Dr. A.R. Barnes and Mr. H.J. Harwick

STAFF OF THE MAYO AERO MEDICAL UNIT

Responsible Investigators

High Altitude Laboratory: Walter M. Boothby, Chairman. Member of the Subcommittee on Oxygen and Anoxia of the Committee on Aviation Medicine, National Research Council.

Acceleration Laboratory:** E.J. Baldes, Vice Chairman. Member of the Subcommittee on Acceleration of the Committee on Aviation Medicine, National Research Council.
C.F. Code, Secretary. Member of the Subcommittee on Decompression Sickness of the Committee on Aviation Medicine, National Research Council.

Investigators

Staff of the Mayo Clinic and Mayo Foundation: (Full time) E.J. Baldes, J.B. Bateman, W.M. Boothby, A.H. Bulbulian, C.F. Code, H.F. Helmholz, Jr., E.H. Lambert, W.R. Lovelace, II and E.H. Wood. (Part time) J.D. Akerman,*** J. Berkson, H.B. Burchell, P.L. Cusick, H.E. Essex, G.A. Hallenbeck, W.W. Heyerdale, H.C. Hinshaw, J. Piccard,*** M.H. Power, C. Sheard, J.H. Tillisch, M.N. Walsh and W.McD. Williams.

Fellows of the Mayo Foundation: R. Bratt, B.P. Cunningham, W.H. Dearing, E.W. Erickson, M.B. Erickson, J.H. Flinn, J.K. Keeley, J. Pratt, F.J. Robinson, R.F. Rushmer, C.F. Schmidt, H.C. Shands, H.A. Smedal, A.R. Sweeney, A. Uihlein, R. Wilder, Jr., J. Wilson and K.O. Wilson.

Officer assigned by the Air Transport Command of the Army Air Forces: K.R. Bailey, pilot

Officers assigned by Air Surgeon's Office: C.O. Benson, Jr., J.W. Brown, J.H. Bundy, D. Coats, E. Eagle, M.F. Green, J.R. Halbouty, R.B. Harding, J.P. Marbarger, M.M. Guest, O.C. Olson, C.M. Osborne, H. Parrack, N. Rakieten, J.A. Resch, H.A. Robinson, H.E. Savely, C.B. Taylor, L. Toth and J.W. Wilson.

Officers assigned by the Navy: W. Davidson and D.W. Gressley.

Officers sent by other governments: J.R. Delucchi, Argentina, and R.T. Prieto, Mexico.

Other investigators: M. Burcham, C.J. Clark, M.A. Crispin, R.E. Jones, C. Knowlton, H. Lamport, C.A. Lindbergh, C.A. Maaske, C.L. Nelson, A. Reed and R.E. Sturm.

Technicians

High Altitude Laboratory: Henrietta Cranston, Lucille Cronin, Ruth Knutson, Eleanor Larson and Rita Schmelzer; Margaret Jackson (from Wright Field).

Acceleration Laboratory: L. Coffey, R. Engstrom, H. Haglund and A. Porter; Ruth Bingham, Velma Chapman, Marjorie Clark, Wanda Hampel and Marguerite Koelsch.

Secretaries

Evelyn Cassidy, Esther Eyrand, Marian Jenkins and Ethel Lettzen.

* Before going into military service.

** The major reports of the Acceleration Laboratory will be published shortly in the monograph entitled "The Effects of Acceleration and Their Amelioration," edited by the Subcommittee on Acceleration of the Committee on Aviation Medicine of the National Research Council.

*** From the Department of Aeronautical Engineering, University of Minnesota.

CONTENTS

Physiological effects of reduced barometric pressure on man.
By W. R. Lovelace, March 21, 1940.

A laboratory aid.
By various Army and Navy officers and Mayo Foundation Fellows assigned to the Mayo Aero Medical Unit, August 1942.

Indoctrination program. Outlines and lectures for beginning and advanced Air Corps personnel.
By R. M. Halbouty and J. A. Resch, August 1942.

Physiologic Effects of Reduced Barometric Pressure on Man

by

W. Randolph Lovelace, II, M. D.

Mayo Clinic
Mayo Foundation, University of Minnesota
Mayo Aero Medical Unit

Condensed from thesis presented March 21, 1940 in partial fulfillment of requirement for degree of Master of Science in Surgery, Mayo Foundation, University of Minnesota. Address given at George Washington University, 1940.

Physiologic Effects of Reduced Barometric Pressure on Man

by

W. Randolph Lovelace, II, M. D.*

The Atmosphere

Atmospheric air, dry, contains 20.93 per cent of oxygen (O_2), approximately 78 per cent of nitrogen (N_2), 0.03 per cent of carbon dioxide (the percentage varies between 0.025 and 0.035), and 1 per cent of the rare and inert gases, argon, helium, neon, zenon and krypton. The total amount of nitrogen and other inert gases is therefore 79.04 per cent. The cause of the uniform mixture of the air is the currents and whirls upward and downward produced by the unequal warming of the earth's surface. With increasing altitude the barometric pressure falls progressively, and the number of gas molecules in every liter of air diminishes correspondingly but the quantitative relationship of the gases in the air mixture does not change, even at an altitude of 72,000 feet.

As far as metabolism is concerned, nitrogen and the rare gases are absolutely inert and under ordinary atmospheric pressure are dissolved in the blood plasma according to their coefficient of solubility at body temperature.

The air has mass, and since it also has weight it is increasingly compressed as the earth's surface is approached. Consequently, the density of the gaseous particles is increased as well as the air density and pressure. The atmospheric pressure is capable of counterbalancing a column of 33 feet of water or of 760 mm. of mercury. Since there is an atmospheric pressure of nearly 15 pounds per square inch at sea level, the body of an average adult is subject to an atmospheric pressure of approximately 30 tons at sea level.

Although widely different conditions may be noted at any given time, the average decrease of temperature is about 1° F. for each 300 feet. The decrease of temperature with altitude is known as the lapse rate. The normal temperature decrease with altitude continues to a level known as the propopause. Below this level lies the troposphere, with its turbulence and infinite variety of weather; above it lies the stratosphere, in which temperature variations are very small, and ideal flying weather prevails.

<u>The most common gas laws</u>. Dalton's law. In any mixture of gases which do not unite chemically, each gas exerts the same pressure as if it were present alone in the volume occupied by all the components and the total pressure of the mixture is equal to the sum of the partial pressure of the gases. The partial pressure of any gas is proportional to its concentration.

When a gas is measured over water, it soon becomes saturated with

*Author has just completed the Civilian Pilot Training Course sponsored by the Civil Aeronautics Administration.

water vapor. From the above law, it is apparent that if the measurement is made under atmospheric pressure the barometric pressure will be the sum of the gas pressure and the water vapor pressure. To obtain the pressure of the gas in question it is necessary to subtract the water vapor pressure from the barometric pressure.

Henry's law. The amount of gas which can be dissolved in a given quantity of water varies directly with the pressure, the temperature being constant.

Dalton's law of solubility of mixed gases. If a mixture of several gases is kept over a liquid, each gas dissolves independently of any of the others and in proportion to its partial pressure.

Boyle's law. The volume of a given mass of gas kept at a constant temperature varies inversely as the pressure, that is, the concentration of a given quantity of a gas at a constant temperature is proportional to the corresponding pressure. For example, a gram of gas occupies double its previous volume when the pressure decreases from 1 atmosphere to 1/2 atmosphere (18,000 feet). The calculation is readily made according to the formula $\frac{P}{760}$, P being pressure.

Charles' law. The volume of a given mass of gas kept under a constant pressure varies directly as the absolute temperature, or, in other words, the concentration of a given quantity of gas under constant pressure is inversely proportional to the corresponding absolute temperature.

Graham's law. At constant conditions of temperature and pressure the rate of diffusion is inversely proportional to the square root of the density of the gas.

Partial Pressure. It was proved quite clearly by Paul Bert, in 1878, that diminution of barometric pressure, such as occurs at high altitudes, affects human beings only when the partial pressure of the oxygen in the inspired air is decreased with consequent subnormally low partial pressure of the oxygen supplied to the tissues by the blood. He also was well aware of the fact that the ill effects resulting from this diminution in pressure can be prevented by the inspiration of air sufficiently rich in oxygen to maintain a normal partial pressure of oxygen. In order to secure adequate oxygenation of the blood, it is relatively unimportant whether the necessary partial pressure of oxygen is obtained by breathing air which contains only 20.93 per cent of oxygen at normal atmospheric pressure, or, for example, by breathing pure oxygen at an altitude of 33,000 feet.

The partial pressure of a gas in a mixture of gases having no action on one another is equal to that which the particular gas would exert did it alone take up the space occupied by the mixture; in other words, in a mixture of gases at a certain pressure, the pressure is divided between the different gases in proportion to their relative volumes. At sea level the

partial pressure of oxygen in dry air is 159.07 mm. of mercury (760 x 20.93). As an airplane ascends, the barometric pressure falls progressively, so that at any given altitude the partial pressure of oxygen is correspondingly reduced. For example, at an altitude of about 18,000 feet the total atmospheric pressure is halved, and, consequently, the partial pressure of oxygen is only approximately 79.5 mm. of mercury (380 x 20.93) although the percentile composition of the air is unchanged. The chemicophysical ability of the oxygen in the air to combine with hemoglobin is essentially dependent on its partial pressure.

(The altitude pressure relationships are shown in table 1, p. 301.)

Respiration

Respiration consists in taking in of oxygen and throwing off the products of oxidation in the tissues, mainly carbon dioxide and water. The oxygen requirements and the amount of carbon dioxide liberated are proportional to the degree of activity of the body; therefore, all other things being equal, the pulmonary ventilation is proportional to the metabolic rate. Thus the alveolar air is maintained at a fairly constant composition. For human respiration only the oxygen fraction of the atmospheric air is important since nitrogen and rare gases are inert and are, therefore, inhaled and exhaled in the same quantity.

The process of respiration by which these two gases are carried through the body is in two parts. External respiration is concerned with the transport of oxygen from the air to the arterial blood and the elimination of carbon dioxide from the venous blood to the outer atmosphere; it keeps the alveoli of the lungs supplied with air of a comparatively uniform composition. Internal respiration transports oxygen between the alveoli and the tissue cells where metabolism actually takes place. It aids in the excretion of carbon dioxide from the tissues to the blood. The lungs, the bronchi, trachea and nasopharynx are primarily concerned with internal respiration.

During inspiration, the thorax is expanded and the lungs are filled by the raising of the ribs and by the descent of the diaphragm. In this manner, air is drawn in through the nose, then into the trachea, the bronchi, and finally into the alveoli. The tidal air, which is the amount of air breathed in or out of the lungs with every quiet respiration, averages about 500 cc. The more the lungs are distended by deep inspiration, the more negative does the pressure in the pleural cavity become. During expiration the thorax collapses, owing to its weight and elasticity of the lungs. The more the lungs are stretched, the greater is their tendency to recoil.

Supplemental air is the additional amount of air which can be exhaled after a normal expiration by a maximal expiratory effort (1500 cc.).

Complemental air is the amount of air that can be inhaled after a quiet inspiration by a maximal inspiratory effort (1500 cc.).

Vital capacity is the sum of the preceding figures, and on the average is about 3500 cc., that is, it is the maximal amount of air that can be inspired after a powerful expiration. It is determined by having the subject make the deepest possible inspiration followed by the deepest possible expiration into a spirometer. The highest of two or three readings is taken as the vital capacity. The vital capacity varies with the sex, weight, age, chest expansion and the size of the individual and the use to which he has put his respiratory mechanism. It is related to the surface area; it amounts to 2.6 liters per square meter for a male and 2.07 liters per square meter for a female. Athletes have a considerably higher vital capacity, and lower readings are obtained in the case of old subjects. It is found that dyspnea develops as the depth of the breathing approaches the vital capacity. The vital capacity is diminished in many diseases, that is, in heart failure, various affections of the lung, like emphysema, pneumothorax and tuberculosis, and in exophthalmic goiter. In such diseases, patients tend to become breathless on exertion more readily than do normal persons.

The residual air is the air which remains in the lungs after a maximal expiration. It can be expelled only by opening the thorax widely and allowing the lungs to collapse.

Alveolar air. As the bronchioles branch and become smaller, their columnar ciliated epithelium becomes modified into a cubical epithelium. The terminal branches are called respiratory bronchioles because in places the normal bronchial wall is replaced by patches of thin flattened cells through which gaseous interchange can take place. Each respiratory bronchiole leads into an expansion, from the vestibule of which arise several passages, the atria. Each atrium leads into two or three air sacs (infundibula); the wall of the air sacs is studded with minute evaginations, the alveoli. The alveoli are lined by large thin flattened cells, but in places clumps of cubical granular cells are seen. External to the lining epithelium are yellow elastic fibers and numerous thin-walled blood vessels. The term "alveolar air" does not refer to the air which is present in the anatomic alveoli, but is used to describe the air in the depths of the lung, which is more or less in contact with the respiratory epithelium and can thus effect gaseous interchange with the blood. Alveolar air is a physiologic and not an anatomic entity. It consists of the supplemental air and the residual air, and amounts to about 3000 cc.

The dead space air is found in the air passages--nasopharynx, trachea, and bronchi. It amounts to 150 cc. It does not come into contact with the pulmonary epithelium and does not effect an interchange with the blood.

Atmospheric air, irrespective of the barometric pressure, becomes saturated with water vapor at 37° C. as it is inspired into the alveoli of the lungs. As barometric pressure is decreased, the alveolar pressure of oxygen decreases at a greater proportional rate than does the partial pressure of oxygen in the lungs because the aqueous vapor in the lungs remains

nearly constant; this is only in part compensated for by the fact that the alveolar carbon dioxide decreases with an increase in elevation. Thus, at 18,000 feet, where the total atmospheric pressure is reduced by a half, the diluting effect of water vapor will be two times as great as at sea level (380 - 47 x 20.93). On the basis of repeated analyses of the alveolar air by the dew point method, Christie and Loomis have concluded that the aqueous vapor pressure in the lungs is 45 mm. of mercury instead of the commonly accepted pressure of 47 mm. They further discovered that the alveolar vapor pressure is lowered by as much as 9 mm. of mercury by hyperventilation, which may be a compensatory factor as it permits a slight increase in alveolar oxygen pressure.

Comparison of the gas pressures in alveolar air and blood (table 2, p. 304) reveals that the pressure differences are such as would enable gaseous interchange to take place by a simple process of diffusion, because of the difference of gas pressure on the two sides of the pulmonary epithelium. The capillaries in the alveoli are so constituted that they furnish a maximum of surface and a minimum of resistance to diffusion of gases; this is essential since the gases of the blood and of the alveoli must come into equilibrium in less than a second. The oxygen pressure in alveolar air averages 104 to 106 mm. of mercury and in venous blood it averages 40 mm. of mercury, thus there is a difference of pressure of more than 60 mm. of mercury on the two sides of the alveolar epithelium. The corresponding carbon dioxide pressures are 40 mm. and 46 mm. of mercury, that is, a difference of pressure of only 6 mm. of mercury. However, the rate of diffusion of carbon dioxide is considerably higher than that for oxygen.

During inspiration the capacity of the lungs is increased and the dead air space followed by the fresh air from the surrounding atmosphere enters the depths of the lungs. The fresh air alters the composition of the alveolar air so as to make up for the changes which have taken place between the alveolar air and the pulmonary blood. It is obvious that the oxygen content of the air in the alveoli is always lower than in the inspired air (table 2). Since the inspired air is always mixed with the air that has remained in the lungs during expiration and which has lost some of its oxygen content and is rich in carbon dioxide and saturated with water vapor.

During expiration the first portion of the expired air has essentially the same composition as room air since it is expired from the "dead space" which includes the nasopharynx, trachea, bronchi and bronchioles up to the place where functioning epithelium is present. The last portion of the expired air approaches in its composition the alveolar air.

Oxygen passes through the living epithelium of the alveoli into the serum and into the hemoglobin of the erythrocytes. Carbon dioxide passes in the opposite direction, its removal from the hemoglobin being facilitated by the entrance of the oxygen. Thus, by simple diffusion through the walls of the alveoli the two gases endeavor to reach a pressure equilibrium and pass from an area of high pressure to an area of low pressure. The essential

condition for an adequate oxygen supply to the blood in the lungs is that the oxygen content and partial pressure of the oxygen in the lungs are higher than they are in the blood returned to the lungs. As pointed out by von Diringshofen, the blood actually loses some of its oxygen to the air in the lungs when a great reduction in the oxygen content of the inspired air occurs above 29,000 feet.

The arterial blood transports oxygen from the lungs to the tissues, and the venous blood transports carbon dioxide from the tissues to the lungs. Oxygen is carried in the blood in two states: (1) a small amount in simple solution according to Henry's law of solution of gases in liquids, and (2) a much larger amount in chemical combination with hemoglobin. The amount of oxygen which the blood will absorb from the air in the lungs and will carry to the tissues will depend in both instances on the partial pressure of oxygen in the lungs. Bohr,[9] in 1905, showed that 100 cc. of blood at body temperature contains, in simple solution, approximately 2.2 cc. of oxygen (S.T.P.D.) when exposed to an atmosphere of pure oxygen. Under normal conditions, with a rather slow rate of circulation, (table 2) the alveolar oxygen pressure averages approximately 14 per cent of an atmosphere, and in the arterial blood it averages approximately 13 per cent of an atmosphere (about 100 mm. of mercury); therefore, 100 cc. of blood contains, in simple solution, about 0.3 cc. of oxygen.

The hemoglobin capacity of 100 cc. of blood, according to the studies of Peters and Van Slyke, averages 20 cc. of oxygen, when completely saturated, but under ordinary respiratory and circulatory conditions it averages only 95 to 96 per cent saturation, which, incidentally, leaves a per cent possibility for further oxygen take-up. Therefore, 100 cc. of arterial blood would contain approximately 19.2 cc. of oxygen combined with hemoglobin and 0.3 cc. in solution, a total of about 19.5 cc. of oxygen, if the subject is breathing air. The oxygen in simple solution is the immediate source from which the tissues obtain their supply.

The pressure of oxygen in the arterial blood is 100 mm. of mercury, and it should be emphasized that this pressure applies only to oxygen in solution. The oxygen pressure in the tissue spaces (table 2) is only 20 to 40 mm. of mercury so that as a result of this difference in partial pressure oxygen rapidly passes out of the plasma through the capillary wall and tissue fluid to reach the tissue cells. The partial pressure of oxygen in the blood falls to about 40 mm. of mercury, and consequently the oxyhemoglobin in the erythrocytes is now exposed to a pressure of 40 mm. of mercury in the surrounding plasma and therefore it can no longer hold all of its oxygen as oxyhemoglobin, hence dissociation of hemoglobin occurs and oxygen is released and diffuses out through the plasma into the tissue spaces. As a result of the preceding phenomenon, the venous blood leaves the tissues with an oxygen pressure of 40 mm. of mercury and an oxygen content of 14.8 cc. per 100 cc.

Carbon dioxide is at a higher partial pressure in the tissue spaces

(46-60 mm. of mercury) than it is in the arterial blood (40 mm. of mercury); therefore, it diffuses out into the blood and its partial pressure rises to 46 mm. of mercury in the venous blood.

Bohr, Hasselbalch and Krogh[10] (1904) made the important observation that the oxygen dissociation curve of hemoglobin is greatly influenced by the partial pressure of the carbon dioxide present. As the blood takes up carbon dioxide in its passage through the capillaries, oxygen is liberated from the oxyhemoglobin more readily than would otherwise be the case.

When the mixed venous blood (oxygen pressure 40 mm. of mercury, carbon dioxide pressure 46 mm. of mercury) reaches the lungs, the oxygen is replaced and the carbon dioxide is given off.

Detailed reviews of the mechanism of oxygen and carbon dioxide transport are given by Haldane and Priestley,[23] Peters and Van Slyke, and Krogh[26].

The method of Haldane and Priestley is used for the collection of samples of alveolar air. The procedure is simply to have the subject make a rapid, sharp and deep expiration through a piece of rubber hose about 3 to 4 feet long and 1 inch in diameter and provided with a well fitting mouthpiece and an automatic spring release type valve, which traps the air in the tube. By means of a very narrow bore rubber tubing connected to a small tube just distal to the metal valve, a sample of the last part of the expired air is then at once taken directly into a gas analysis apparatus, or else into an evacuated mercury sampling tube. When taking a sample of alveolar air, it is important that the rate and depth of breathing should be normal until the moment when the deep expiration is made.

Haldane and Priestley have given a thorough description of the effects on human beings of ascent to a high altitude. When the barometric pressure is rapidly reduced, the depth and frequency of breathing are increased at first, but after several minutes this increase diminishes markedly. As a direct result of the increased breathing, there is a fall in the alveolar pressure of carbon dioxide and more carbon dioxide than usual is washed out of the blood. This causes the respiratory quotient to be increased temporarily from the normal value of 0.8 to as much as 2.8 when the onset of anoxemia is sudden and marked. The elimination of carbon dioxide through the lungs decreases the stimulus to the respiratory center and causes the respiratory minute volume to fall. Then the extra elimination of carbon dioxide from the blood begins to lessen. In the early stage of ascent, therefore, pulmonary ventilation is greater than normal and the alveolar pressure of carbon dioxide is less than normal and oxygen pressure is slightly increased. Later, the alveolar pressure of oxygen falls from the level at which it was maintained during the initial excess breathing, since the rate of absorption of oxygen remains undiminished, while the pulmonary ventilation falls. The drop in the alveolar pressure of oxygen tends to increase the symptoms of anoxemia and thereby to increase the breathing, but finally a balance is reached, at least temporarily. If the anoxemia is produced gradually the

initial marked increase of breathing is unnoticeable as the extra carbon dioxide is washed out gradually.

Haldane and Priestley further found that the new lower level of alveolar pressure of carbon dioxide becomes the regulating level for the atmosphere breathed. A small increase above this level results in a great increase in breathing while a small diminution causes apnea. The primary and marked increase in breathing was attributable to the alveolar pressure of carbon dioxide in the entire body being above the new level and the quieting down of breathing was a result of the gradual washing out of carbon dioxide until a new normal level was attained, which was itself determined by the secondary effects arising from the decreased pressure of the alveolar oxygen. Anoxemia tends to increase breathing but the increased breathing, by washing out carbon dioxide, quickly stops this increase, so that after a time there is only a small increase. Since the alveolar air during normal breathing contains about a third less oxygen than does the inspired air, it follows that when the partial pressure of oxygen in the inspired air is reduced a third, the percentage of oxygen in the alveolar air will be reduced to about half. Comparison of this figure with the dissociation curve of oxyhemoglobin shows that this diminution corresponds to an arterial saturation of approximately 90 per cent and that any further decrease will be followed by a rapid and dangerous fall in saturation. Haldane and his co-workers [24] were among the first to point out that the responsive breathing to a given reduction of pressure of oxygen in the inspired air varies considerably among different individuals. Those who respond by increased breathing are, therefore, more protected against the onset of anoxemia because of the relatively higher percentage of oxygen in their alveolar air. Christensen and Krogh, [18] in comparing a group of pilots who could tolerate very high altitudes with a group of those who could not, found that among the former there were greater pulmonary ventilation, a distinctly lower partial pressure of carbon dioxide, and a higher alveolar pressure of oxygen. The larger ventilation indicated that there was less difference between inspired and expired oxygen than there would be among average individuals. Haldane and Priestley further stated that if the carbon dioxide pressure in the respiratory center falls below a certain level, the center ceases to respond even to an excessive degree of oxygen want and is soon severely damaged.

Symptoms and Effects of Oxygen Want

The symptoms of anoxemia are well known and have been determined from numerous studies made on expeditions to high altitudes, in the mountains, in low pressure chambers, in low oxygen chambers, with rebreathing apparatuses, and also on ascents by balloon and airplane. In a comprehensive and extensive report on the effects of deprivation of oxygen, McFarland [34] listed the most frequently encountered subjective symptoms as follows: headache, respiratory changes and difficulties, excessive sleepiness, vertigo or dizziness, difficulty in concentrating, sensory impairment, lassitude and indifference, and fatigue. He listed the following important variables which may affect the response of a pilot to the lowered oxygen pressure at high altitudes: rate of

ascent, height attained, length of exposure, amount of physical exertion, movement of the plane and the physical characteristics of the individual.

Since anoxemia is of slow and insidious onset, the various senses and the intellect gradually become clouded without the individual perceiving the change. For this reason, it has been difficult in the past to convince pilots that they are inefficient at high altitudes. When such individuals go up without oxygen, remain at a considerable elevation for some time, and then begin to take oxygen for the first time, they are amazed at the sudden and dramatic increase in their powers of perception and sensation in general. Armstrong [1] has considered in detail the major problems resulting from anoxia in aviation, and also has considered the effect of repeated daily exposures to anoxemia.

At different heights the "interval of reserve," that is, the time until the occurrence of symptoms after cutting off oxygen, shows a distinct individual variation. Ruff and Strughold,[38] in Germany, found that this interval differs greatly in the case of different individuals and varies for the same person according to his physical condition. At 16,400 feet this interval of reserve varied from five minutes to more than one hour for different individuals; at 19,600 feet it varied from a few minutes to half an hour, at 22,900 feet it varied from one minute to half an hour, and at 26,200 feet it varied from ten seconds to fifteen minutes.

The symptoms of anoxemia are often compared with those of alcoholic intoxication because of the close similarity of the two in many respects. The pilot and also the physician who is conducting tests in an airplane or in a low pressure chamber are almost always convinced that they are normal in every respect, even at extreme altitudes, and they seldom lack confidence or assurance. Some individuals become euphoric, others morose, and still others pugnacious and unwilling to listen to advice. The capacity for self-criticism is soon lost. Even a physiologist of Haldane's caliber insisted on keeping a pressure of 320 mm. of mercury in a low pressure chamber experiment, although he had great difficulty in making observations, was cyanotic, and could hardly calculate his pulse rate from observations made for twenty seconds. After an hour and a quarter at this pressure, he was still determined (fixed idea) to remain in the chamber, but when he consented to an increase of pressure to 350 mm., he began to regain his faculties. Even then, when he attempted to look at his reflection in a mirror, some time elapsed before he realized that he was looking at the back, and not at the front, of the mirror. When he was questioned later he had no recollection of his long stay at 320 mm. and was unreasonable, somewhat unsteady, and had a headache for several hours. Haldane and Priestley also explained that at low pressures the diffusion of oxygen molecules within and into the pulmonary alveoli is more free than would be the case when breathing in the same percentage of oxygen at sea level.

When the oxygen supply is inadequate the aviator concentrates exclusively on one particular aspect of his problem and forgets all other

essentials of a normal procedure. At 300 miles or more per hour in an airplane, fixed ideas may well eventuate in disaster.

Many individuals can take a few drinks and seemingly can drive an automobile well. Somebody else, after the same number of drinks, will weave down the road at a high speed, insisting all the time that he can drive safely and knows exactly what is going on. McFarland and Barach[35] pointed out the relationship between alcoholic intoxication and anoxemia. In 80 per cent of twenty-three subjects who had ingested from 0.75 to 1.5 gm. of alcohol per kilogram of body weight, inhalation of 50 per cent oxygen, mixed with 2 to 5 per cent carbon dioxide, lowered the alcohol and lactic acid content of the venous blood. There also was a corresponding improvement in mental and motor behavior. Two subjects who complained of nausea, headache, inability to retain liquids, and general malaise on "the morning after" were treated in the laboratory with inhalation of 100 per cent oxygen. Within 45 minutes there was marked subjective improvement and the subjects were able to take fluids and nourishment readily.

Barach's[3] paper on the relationship between anoxemia and pilot error vividly called the attention of the medical profession and of individuals connected with commercial aviation to the dangers that could arise from oxygen want and the possibility of accidents arising therefrom. Barach and his co-workers carried out a study on the effects of deprivation of oxygen on the ability to do multiplication and division on a slide rule during four hours at a simulated elevation of approximately 12,000 feet, in an oxygen chamber. They found that the number of problems solved by three of four subjects was decreased. There was also a tendency toward boisterousness and excessive loquacity. The use of oxygen by aviators flying at, or above, 12,000 feet was recommended.

Campbell and Poulton[16] stated that when the oxygen pressure in the inspired air falls below 14 per cent the oxygen pressure in the tissues of normal individuals begins to fall. Haldane and Priestley found that the barometric pressure must be reduced by about a third before there is any evident effect, at the time, on the breathing and the carbon dioxide pressure of most normal individuals, and that this effect differed according to the rapidity at which anoxemia was produced. The oxygen pressure in the inspired air at 10,700 feet (508.5 mm. of mercury) is approximately the equivalent of only 14 per cent oxygen at sea level and therefore it can be assumed that tissue anoxemia would begin at this point in the case of a perfectly normal individual with an efficient and adaptable cardio-respiratory system. This may be designated as the critical level. In this connection, reference to experiments by Dill, Christensen and Edwards, showing the relation between arterial saturation and the alveolar pressure of oxygen, reveals that the average alveolar pressure of oxygen at this altitude is about 60 mm., as was the case in experiments reported by Boothby, Lovelace, and Benson. At an alveolar pressure of oxygen of 60 mm., the investigators named found that the hemoglobin of the arterial blood was, on the average, about 90 per cent saturated. They were also of the opinion that at high altidues the partial

pressure of oxygen in the arterial blood, measured by referring its percentage saturation with oxygen to the dissociation curve of the same specimen of blood, is approximately equal to that in the alveolar air. In addition, these investigators fully confirmed the fact that diffusion alone can account for the transfer of oxygen in the lungs, and that the oxygen saturation of arterial blood does not necessarily increase during acclimatization.

Campbell [17] listed the following factors as being in control of tissue oxygen tension: oxygen pressure in the inspired air, quantity of hemoglobin, circulation rate and vascular adjustment, and diffusion and secretion through the lung and through the capillary walls in the tissues and oxygen metabolism. It is well known that the body is unable to store oxygen to any appreciable extent.

The effects of being just above the critical level at which tissue anoxemia occurs if individuals are normal is strikingly exemplified by the following experiments. These important experiments on the effect of repeated exposure to an altitude of 12,000 feet were carried out by Armstrong and Heim [2]. Before reporting the experiments themselves, it should be said that at an altitude of 12,000 feet the inspired air contains an equivalent oxygen percentage of 13.31. Armstrong and Heim exposed normal, intelligent and cooperative subjects of an average age of twenty years to a simulated altitude of 12,000 feet above ground level for four hours daily, six days a week, for twenty-seven days. They condluded: "(1) Each exposure produced a concurrent mental and physical fatigue which persisted for approximately twenty-four hours and was manifested by difficulty in mental concentration, retention, and attention over periods of time in excess of a few minutes; by sleepiness and lassitude; by errors in construction, spelling and composition; and by lack of initiative. (2) repeated daily exposures produced a continuous mental and physical fatigue throughout each twenty-four hour period with manifestations similar to those mentioned above. In addition, nervous irritability was increased." They recommended that flying personnel take oxygen at all times when flying at or above 12,000 feet.

Uihlein and I [32] conducted a series of tests, as yet unreported, on a Link trainer, which is a mechanical device for training pilots to fly by instruments and to use the radio ranges and other modern aids to air navigation and which resembles a small, hooded airplane with fuselage, wings, ailerons and the tail section. The controls and instruments in this device are essentially the same as those on a modern airplane. We exposed experienced pilots to simulated altitudes of from 10,000 to 20,000 feet over periods from 30 minutes to 4 hours by having them wear a large gas mask which completely covered the face but had glasses through which the pilot could see. The percentage of oxygen in the inspired air was carefully controlled by running in a mixture of nitrogen and oxygen from two separate tanks and repeatedly testing the percentage composition of the mixture by the Boothby modification of the Haldane apparatus, and thereby determining the simulated altitude. After 30 minutes to 1 hour on the Link trainer at simulated altitudes of 15,000 feet and higher, the majority of the pilots complained of

fatigue and exhibited signs of tenseness, as shown by over-controlling the Link trainer, and there was definite slowing of the mental processes, as shown by the increased time it took to solve the various orientation problems. Three of the ten pilots tested became lost, one at 16,000 feet after 40 minutes, one after one hour and fifteen minutes at 15,300 feet, and one after one hour and forty-five minutes at 18,000 feet, and were unable to determine their position until they were given oxygen. Further tests are to be carried out on the Link trainer at various altitudes for more prolonged periods of time. Officials conducting investigations into the cause of airplane crashes should always give due consideration to the possible part that anoxemia may have had in causing the accident, and they should investigate the efficiency of the oxygen apparatus installed in the plane.

Necessity for Oxygen at Various Altitudes

At 28,800 feet the barometric pressure is 238.1 mm., of which approximately 21 per cent, or 50 mm., represents the partial pressure of oxygen in the outside air, that is, the air to be inspired. In the lungs, however, the air will contain 47 mm. of water vapor and 40 mm. of carbon dioxide as a result of absorption of 40 mm. of oxygen at R.Q. of 1.0 for utilization by the cells in combustion and (assuming no acclimatization or temporary compensation by increased respiration) the partial pressure of oxygen in the lungs, therefore, would theoretically be zero, calculated according to the formula which will be given. Of course, without previous acclimatization and training in how to breathe, the subject could live only a few minutes, even by excessive breathing.

At 20,000 feet the barometric pressure is 349.1 mm., of which approximately 21 per cent, or 73 mm., is the partial pressure of oxygen in the inspired air. In the lungs, provided the body has no means of compensating temporarily by breathing more deeply, the partial pressure of oxygen would be only about 23 mm., calculated according to the formula which is given shortly. However, as shown by experiments in a low pressure chamber, the body can compensate for a brief period by excessive breathing, and the oxygen can be raised to approximately 36 mm. The time element comes in at this point because one cannot compensate by increased breathing to this degree for more than 15 to 30 minutes without development of fatigue and acapnia, with danger of cessation of respiration followed by death. Toward the end of the experiment the alveolar carbon dioxide is falling fast; this change indicates that the danger of acapnia is near.

The theoretical partial pressure of oxygen in the alveoli of the lungs can be calculated by the formula: $(O_2)_p = \left[(B - V.P.) \times O_2\right] - (CO_2)a/R.Q.$

where $(O_2)_p$ = pressure of oxygen in alveoli of lungs

V.P. = vapor pressure saturation at body temperature (37° C.) = 47 mm.

B. = barometric pressure

O_2 = relative concentration of oxygen in air = 0.21 per cent, or, more exactly, 0.2093

$(CO_2)_a$ = average pressure of carbon dioxide in alveoli of lungs = 40 mm.

R. Q. = respiratory quotient.

and where all pressure values are expressed in millimeters of mercury.

Example: Breathing air with R.Q. of 1.0 at sea level

$$(O_2)_p = \left[(760 - 47) \times 0.21\right] - 40/1.0 = 109$$

It is important to note that the averages of the determination of the alveolar oxygen at ascending altitudes made in the low pressure chamber correspond very closely to the theoretical curve up to about 12,000 feet. Above this elevation the partial pressure of oxygen in the alveoli becomes increasingly higher than the theoretical curve; the latter is based on the assumption that the body does not compensate. However, the fact that there is a corresponding decrease in the alveolar carbon dioxide pressure indicates that the body actually is able to compensate to a certain limited degree by hyperventilation. A similar tendency for the body to compensate is evident in the carbon dioxide curve in McFarland's data.

The average alveolar oxygen pressure in the lungs can be increased definitely by slow deep breathing and the aviator's "ceiling" increased temporarily by as much as 1000 or 2000 feet. It must be observed, however, that the alveolar oxygen increases and alveolar carbon dioxide decreases with deeper respiration. The decrease in carbon dioxide is dangerous because through its effect on the hydrogen-ion concentration of the blood it is a direct respiratory stimulant and is the chief factor in rendering breathing automatic. When the alveolar carbon dioxide is decreased, if the aviator is absorbed in fighting he may forget to breathe voluntarily and become unconscious from lack of oxygen before there is an automatic stimulation of respiration by reaccumulation of carbon dioxide.

<u>Oxygen consumption; rate of respiration, and rate of ventilation</u>

These are all essentially unaffected by changes in barometric pressure provided the development of anoxia is prevented by inhalation of oxygen.

In this paper, several references have been made to the fact, well known to physiologists, that lack of oxygen is not a respiratory stimulant and that a subject will show no distress and slight increase in rate or depth of respiration from continuing to breathe decreasing concentrations of oxygen. This is very important to aviators because flyers may become unconscious at high altitudes without knowing that they are in danger. At the end of one experiment, with the subject breathing decreasing concentrations of oxygen, he was cyanotic owing to lack of oxygen and was already beginning to lose consciousness and would have done so completely in another few seconds if the experiment had not been terminated instantly. The great danger was the fact

that he did not realize that he was in danger because he experienced no discomfort or distress even toward the end of the experiment. This entire experiment was only about 27 minutes long, and the subject of the experiment was above the simulated altitude of 15,000 feet only six minutes--a continuation of another minute and the subject might have collapsed and might not have recovered. This is a dangerous type of experiment to conduct and should only be done by physicians thoroughly conversant with these dangers.

Contrast the results of this experiment with those in cases in which the subject is breathing increasing concentrations of carbon dioxide with ample oxygen where the respirations are markedly increased with great respiratory discomfort and distress as a result of increase in carbon dioxide from rebreathing oxygen without removal of the carbon dioxide by soda lime. Carbon dioxide, through the fact that it increases the hydrogen-ion concentration of the blood, is the chief regulator of the respiratory mechanism as was shown by Haldane and Priestley.

Carbon Monoxide

The affinity of carbon monoxide for hemoglobin is approximately 300 times as great as that of oxygen. Carbon monoxide poisoning produces a more marked lowering of the oxygen pressure in the tissues than that produced by bleeding, hemolysis, or inspiring air with half its normal percentage of oxygen since the oxyhemoglobin still left gives up its oxygen less readily than normal oxyhemoglobin. Douglas, Haldane and Haldane (1912) showed that the presence of carbon monoxide hemoglobin causes the dissociation curve of the functioning hemoglobin which is still present to shift to the left and the characteristic S shape disappears. As a consequence, hemoglobin has a stronger hold on oxygen and will only release it to the tissues in appreciable amounts when the oxygen pressure is very low. For adequate treatment, high concentrations of oxygen are indicated in order to displace the carbon monoxide from its union with the hemoglobin by mass action of the excess oxygen.

Cardiac Disease

In a recent study on the effect of decreased barometric pressure on the electrocardiogram, Benson (7) found that when air is breathed by a normal subject, increased rate is seen in the electrocardiogram, beginning at about 8,000 feet and increasing as the altitude is raised. The rate promptly returns to normal when oxygen is breathed up to and including 20,000 feet (Bar. 349); without oxygen, only a very slight and inconstant depression of the T wave and decrease in amplitude of the QRS complex were observed in the case of healthy subjects.

As a result of these observations and deductions from the literature on the subject, Benson felt that patients with cardiac disease and persons with silent and unknown coronary disease can fly in commercial aircraft provided oxygen in adequate amounts is supplied by an efficient inhalation

apparatus at altitudes in excess of 8,000 feet. Passengers who complain of respiratory distress or pain in the thorax while in flight should be immediately supplied with oxygen as a precuationary measure. Patients with decompensated cardiac disease should receive oxygen continuously. The fact that the action of the heart of a young healthy subject will quickly return to normal after oxygen has been administered at 20,000 feet does not necessarily apply to the pathologic heart. Anginal attacks have been induced by lowering the oxygen tension of the inspired air, and Graybiel and his co-workers have called attention to the untoward effects of low oxygen tension in cases of cardiac disease, which may be accentuated by the general physical unfitness so commonly associated with heart disease. Benson has reported the case in which a pilot had an initial and fatal attack of angina pectoris while flying at only 11,000 feet.

Graybiel and his co-workers made a study of the effects of experimentally induced asphyxiation on cardiac patients. These patients were subjected to an oxygen tension corresponding to an altitude of 14,500 feet for a short period. Although there were no subjective symptoms, three of the thirteen patients fainted, and four others exhibited signs of cardiac distress. The investigators concluded that many cardiac patients are in danger when the oxygen of the inspired air falls to 12 per cent or less. Levy, Barach and Bruenn, after observing the effects of the inspiration of air containing only 12 per cent oxygen by patients with cardiac pain, concluded that persons known to have cardiac disease should not be allowed to go on flights at high altitudes unless proper provision had been made for supplying an adequate amount of oxygen at all times.

White, on the basis of experiments on the effect of anoxia in high altitude flight on the electrocardiogram, recommended 7,500 feet as a minimal level above which oxygen would be required.

It is agreed that patients with known cardiac disease are in definite danger from anoxemia such as occurs in airplanes. It must be emphasized that there are many types of cardiac and respiratory lesions that may exist among, but that are unknown to, individuals who are intending to fly. It is accepted that many patients who have cardiac and respiratory diseases are on the verge of anoxemia at sea level, so that even a slight increase in elevation would rapidly bring them into a state of anoxemia. Fortunately, it is now unnecessary to subject passengers to these risks, since they can travel in perfect safety and comfort by using an efficient inhalation apparatus for the administration of oxygen. It is most important that passengers of this type use only an apparatus that is capable of maintaining them in the condition which exists at sea level, as far as oxygen is concerned.

Effect of Sulfonamides on Pilots

Pilots who are receiving sulfonamide compounds should be grounded until the course of therapy is completed and until they have returned to a normal

condition. This is especially true in the case of pilots with a definite history of severe sensitivity to sulfonamides.

The reason for grounding pilots taking this group of drugs is the toxic effects that may occur and require careful usage of the drugs and close daily observation of the patients. Nausea and vomiting are the most constant symptoms of toxicity. Cyanosis and drug rashes are occasionally observed, as is drug fever. Cyanosis is believed partly due to the formation of methemoglobin and this further reduces the oxygen-carrying power of the blood. Jaundice and toxic hepatitis rarely occur. The most important of the toxic manifestations, which are attributable to affection of the central nervous system of pilots are headache, vertigo, malaise, mental depression and rarely a toxic psychosis. Any one of these manifestations would make it unsafe for the individual to pilot an aircraft. The mental reactions may occur early or late and generally disappear very quickly when the drug is discontinued. Ambulant patients should not even drive an automobile because of the possible reduction in mental alertness. These mental symptoms are generally accentuated by altitude according to observations made on passengers on a large commercial airline.

Equally important toxic effects are agranulocytosis or neutropenia and acute hemolytic anemia. Daily blood counts and hemoglobin determinations are an absolute requisite if these reactions are to be detected early. The danger of anemia to pilots has been discussed elsewhere in this paper. No pilot should be allowed to fly until all evidence of toxic manifestations has subsided.

In a recent discussion before the Aero-Medical Society in 1939, I [29] described the case of a pilot who had to turn over the controls of an airplane to the co-pilot at an elevation of 13,000 feet. His physician had made a diagnosis of acute pharyngitis and laryngitis four days previously, and since then, the pilot had taken 160 grains (10.6 gm.) of sulfanilamide. The pharyngitis and laryngitis had cleared up, but his "ceiling" had been reduced as the result of toxic manifestations and he found it impossible to pilot the flying boat at 13,000 feet. As a result of this observation a major airline made a ruling that no pilot shall fly while being treated with sulfanilamide or similarly acting drugs. Likewise, passengers who have been taking any of this group of drugs should be given oxygen at relatively low altitudes.

Aeroembolism

Aerial warfare, with perfection of new types of bombing, pursuit and interceptor airplanes, now may take place at altitudes of 30,000 to 40,000 feet. The speed and rate of ascent of many of these aircraft expose their pilots to a new danger, in addition to the well-known danger of anoxia.

Armstrong (1939) defined aeroembolism as a disease produced by a rapid decrease of barometric pressure below 1 atmosphere, such as may occur in aircraft flights to high altitude, and which is marked by the formation of

nitrogen bubbles in the body tissues and fluids.

Prevention of Aeroembolism

On account of the serious discomfort resulting from aeroembolism, Boothby, Lovelace and Benson [13] have devoted their efforts to developing a practicable method of prevention by removal of the majority of the nitrogen in the body by the inhalation of 100 per cent oxygen just before ascent. A preliminary report of our work was presented by me at the Annual Meeting of the American Association for the Advancement of Science in 1939. Up to the present time, in the low pressure chamber in Rochester, 102 ascents have been made to an altitude of 30,000 feet, eighty ascents to 35,000 feet, and thirty ascents to 40,000 feet. Although the simulated high altitudes as a rule were maintained for only a short time (ten to thirty minutes), in one instance two subjects remained at 35,000 feet for two hours and fifteen minutes.

In some of these simulated ascents a certain train of symptoms were observed which were considered suggestive of aeroembolism. These symptoms were light-headedness, smarting and stinging of the conjunctiva, and formication and pains in extremities, around the joints or along the tendon sheaths or nerve trunks. None of our subjects has been paralyzed, become unconscious or experienced symptoms of such severity as to cause alarm; however, as soon as any of the symptoms appeared the simulated ascent was not only immediately stopped but the subjects usually descended about 5,000 feet or until the symptoms disappeared.

The next step in the investigation was to combine the inhalation of oxygen with exercise. It was then found that symptoms no longer occurred, even if the period of decompression was reduced to thirty minutes, provided the exercise was the equivalent of walking at three miles per hour on a treadmill accompanied by considerable movement of the arms. The symptoms occurred occasionally when the decompression time was shortened or the intensity of the exercise was decreased and the rapidity of ascent increased. The maximal rate of simulated ascent was 4,700 feet per minute.

Aural Distress

Among those accustomed to flying, it is well known that the most common subjective complaint of both airplane pilots and passengers is discomfort in the ears associated with ascent during flight. Lovelace, Mayo and Boothby (1939) successfully used inhalation of 80 per cent helium and 20 per cent oxygen as an adjunct in the prevention or treatment of aero-otitis media. Inhalation of this mixture through the B.L.B. inhalation apparatus, when descending from elevations of 12,000 feet or with sufficient extra oxygen added at higher elevations, may be used to prevent aural distresses because the rate of diffusion of helium is 2.7 times that of nitrogen; the helium will diffuse more rapidly through the eustachian tube than will air. More nearly similar pressures on both sides of the tympanic membrane can be

maintained in this manner. As a result of this suggestion the test pilots of a major airplane manufacturing company almost routinely inhale helium and oxygen during rapid descents.

Types of Inahalation Apparatus

Closed circuit system. The most economical principle for the administration of oxygen is, of course, the closed circuit system. By such a system is meant a closed, circuitous pipe line, whose inside diameter is approximately 1 inch, with an expansible chamber of bag of a capacity of not less than 5 liters for a single individual, although this ratio would not have to be maintained for multiple units; a container for soda lime or similar substance for absorbing carbon dioxide; a circulating pump if the system is multiple, or a properly placed inspiratory-expiratory valve when the system is constructed for use by only one individual, and an absolutely air-tight face mask. Large reducing valves and automatic controls must be furnished to regulate the supply of oxygen. Both in the laboratory and in level flying, this type of apparatus is particularly economical, as theoretically the total amount of oxygen needed should not exceed the amount of oxygen each individual actually burns, that is, approximately 0.25 liters at standard temperature and pressure dry (S.T.P.D.) per minute for a pilot who is relatively inactive and 0.7 liter (S.T.P.D.) per minute for an active member of the crew working or moving about in the plane.

The practical objection to the closed circuit system is that air can easily leak into the system around the mask or at many other places, causing a dangerous accumulation of nitrogen. For this reason, the method is not used in commercial aviation. Furthermore, the economy in the use of oxygen is not as great in aviation as one would at first suspect from theory, because of losses occurring during rapidly alternating ascent and descent. During descent the oxygen in the system will be compressed and the volume decreased, thus automatically activating the oxygen supply valves. On the following ascent, the oxygen would expand with the decrease in barometric pressure, and the oxygen would be lost through the escape or pressure safety valves. Rapid alternation of such procedure would be very wasteful of the oxygen reserves.

Open circuit apparatus. The other type of apparatus is known in the physiologic laboratories as an "open circuit apparatus," that is, the air is inspired with the addition of an appropriate amount of oxygen and then expired directly into the surrounding air with only a very small, incidental amount of rebreathing. In the open circuit type of apparatus, no attempt is made to remove the carbon dioxide so that no more than a very small amount of the expired air with its enriched oxygen content can be used again.

However, such a system, to be economically of practical value in aviation or in clinical medicine for administration of oxygen, must contain a reservoir bag, in order to collect, save and have ready for use, on the next inspiration, the oxygen that has been flowing from the tank during

expiration. As the major part of the inspiratory phase of respiration is only from a third to a fifth of the respiratory cycle, it is obvious that unless such provision is made, only a third to a fifth of the oxygen supplied can be utilized. This point is emphasized because many persons wonder about the necessity of a reservoir bag. Failure to use more than a third to a fifth of the oxygen flow is one of many reasons why the old-fashioned "pipestem" method was so inefficient and now is little used.

However, to prevent the accumulation of an excessive and unbearable amount of carbon dioxide in such a reservoir bag, one must either use a small bag with a capacity somewhat less than the average amount of air expired normally, or else prevent, by other rather complicated means, the expired air from entering a larger bag. This reservoir bag is preferably placed close to the mask. However, it can be placed at the end of a long corrugated rubber tube (1 inch in diameter) provided that the capacity of the bag does not exceed 450 to 600 cc.; provided that the intake of fresh oxygen is led directly into the bag, and provided that the automatic sponge rubber air regulator or expiratory valve is close to the mask. For most purposes, both in aviation and in therapy, it is preferable to have the bag attached directly to the mask.

B.L.B. oxygen inhalation apparatus. The B.L.B. oxygen inhalation apparatus, which was developed by Boothby,[11] Lovelace [28] and Bulbulian [15] in 1938, was modified by Boothby, Lovelace and Uihlein [14] in 1940. At present, it consists of three separate parts: (1) the mask which is of the nasal or oronasal type; (2) the regulating device, by means of which the proper quantity of air is permitted to enter the apparatus, so that any concentration of oxygen desired can be obtained automatically without the wearer's experiencing any significant resistance at any phase of the respiratory cycle, and (3) a reservoir rebreathing bag, which conserves the oxygen (flowing from the reducing valve and flowmeter on the oxygen cylinder) without loss during the expiratory phase of respiration, (normally about two-thirds to three-fourths of the respiratory cycle) and which at the same time automatically permits some reuse of the enriched oxygen mixture without undue or annoying accumulation of carbon dioxide. These three parts are constructed in relationship to each other for the greatest possible efficiency in the utilization of oxygen.

A new principle in respiration apparatus is used in the present B.L.B. apparatus. Advantage has been taken of the fact that a porous sponge rubber disk will produce sufficient resistance to the passage of air so that, during expiration, the light rubber reservoir rebreathing bag will fill completely before any appreciable amount of the inflowing oxygen and expired air will pass out of the apparatus through one of the sponge rubber disks. However, the resistance of the sponge rubber to passage of air is so slight that as soon as the reservoir bag is distended by the first part of the expired air, which is rich in oxygen and poor in carbon dioxide, the remainder of the expired air will pass out of the apparatus without any significant increase in resistance to normal expiration, and, conversely, on inspiration, the

subject can barely detect an increased resistance to complete inspiration in those instances in which the addition of a large proportion of air is desired in order to obtain comparatively low concentrations of oxygen. In brief, the sponge rubber disk acts, with barely appreciable resistance, as a combined inspiratory-expiratory valve and has an efficiency of approximately 98 per cent. It is called an "automatic air regulator." The two sponge rubber disks are retained in a convenient position on the inhalation apparatus by means of proper sized receptacles molded directly in the rubber mask.

When using the B.L.B. apparatus at low altitudes, mixtures of air and oxygen are used; at altitudes of more than 30,000 feet, practically pure oxygen is breathed. By a proper setting of the oxygen flow the amount of additional air required at the lower altitudes is supplied automatically through the sponge rubber disk.

The nasal type of mask with the mouth free for talking or eating is preferable for use on commercial airlines, both for crew and passengers, as the elevations to which they ascend rarely exceed 15,000 feet. For military aviation, an oronasal type of mask is preferable in order to avoid the danger of unconsciousness resulting from mouth breathing at the higher altitudes.

The experimental data of Boothby, Lovelace and Benson (13) show that the amounts of oxygen recommended are sufficient to maintain an essentially normal concentration of alveolar oxygen (between 80 and 120 mm.) for all elevations up to and including 35,000 feet, when the aviator is sitting and doing work comparable to operating a plane under normal air conditions. The experiments that show rather high results probably would be obtained in actual flight when the aircraft was being controlled by the automatic pilot and the lower results, when the pilot is actually flying the plane. Theoretically, when inhaling pure oxygen the aviator should have a normal alveolar oxygen pressure at 33,000 feet; the data show, on the average, that this is true and even up to 35,000 feet in no single experiment was the alveolar oxygen pressure below what it would be at 6,000 feet without inhalation of oxygen.

The data for 40,000 feet show that the alveolar oxygen pressure, in the few determinations that were made, corresponds to pressure that would be obtained by testing a pilot breathing air without an additional supply of oxygen at 11,000 feet. In fact, the data are even slightly above the line representing the theoretical value for breathing pure oxygen. This is due to the fact that the compensatory increase in the rate and depth of respiration elevates slightly the average alveolar oxygen pressure. The entire series of experiments give definite proof of the efficiency of the B.L.B. oxygen inhalation apparatus.

In table 3 (p. 305) there are indicated under the heading "aviator, inactive," the minimal rates of oxygen flow needed by an aviator at various altitudes using the B.L.B. oxygen apparatus while sitting and piloting his

plane with a minimal amount of muscular exertion. Under these conditions, an aviator of average size would be consuming about 250 to 300 cc. (S.T.P.D.) of oxygen per minute, measured at standard temperature (0° C.) and pressure (760 mm.) dry. Under the heading "aviator, active," is given the amount of oxygen needed for a pilot under conditions of rather difficult navigation or for a machine-gunner firing but not doing a great deal of lifting or moving about. These degrees of work would roughly correspond to an oxygen consumption of 400 to 500 cc. per minute (S.T.P.D.). Under the heading "aviator, very active," is given the amount of oxygen needed for a pilot or machine-gunner working rather strenuously. This is estimated to be between 500 and 600 cc. per minute (S.T.P.D.). This degree of work would correspond to that of a man walking at a rate of approximately 2 miles per hour. For each value as expressed at S.T.P.D. the value to which this amount of oxygen expands in the lungs of the aviator at each altitude is also given.

Other types of inhalation apparatus. Administration of oxygen to aviators by the commonly used tube and pipestem method is inefficient and expensive. The primary drawback to taking oxygen through a tube is that a normal individual ordinarily exhales from half to two-thirds of the time, so that half to two-thirds of the oxygen which comes through the tube is lost. In addition, considerable training is required to get an individual to breathe in only through the tube. No matter how well trained he is, there is no way of controlling the amount of outside air breathed in during undue stress or excitement. Naturally, the higher the pilot goes, the greater will be the danger of breathing in atmospheric air and the more chance there will be for the development of sudden, severe anoxemia; in fact, at high altitudes, if the tube should drop out of the pilot's mouth he might become unconscious in one minute. There is also a frequent complaint of irritation of the mucous membrane of the mouth and throat and of salivation. Moreover, it is difficult and dangerous to talk over the radio while using such equipment and the apparatus is in the way during acrobatic maneuvers. It is admitted that a pilot, or, for that matter, a physician, is unable to recognize the onset of symptoms of anoxemia, which can occur very easily when the oxygen is taken inefficiently by this method.

Extensive research is now being carried out on a demand type of apparatus in which the oxygen would be supplied only on inspiration.

Emergency Parachute Escape

Parachute jumps from 35,000 to 40,000 feet are made whenever abandonment of the ship is necessary to save life. After the necessity for bailing out arises, a minute probably elapses before the preparation to jump can be completed. At an elevation of much more than 35,000 feet, cerebral anoxia would be present at the end of a minute without oxygen, and unconsciousness would begin to come on. In a case in which a test pilot took off his oxygen mask at an altitude of 35,000 feet in the low pressure chamber at the Mayo Clinic and then went through the motions of leaving a plane, unconsciousness and convulsions occurred in forty seconds. Even if the aviator descended as

a free falling body until he reached 20,000 feet, he would in the second minute become unconscious and therefore be unable to pull his rip cord. On the other hand, if he pulled his rip cord within a few seconds after he left his plane, it would take five to ten minutes to descend to where he would have sufficient oxygen to live, and then he would have little chance of regaining consciousness. Therefore, a parachutist must be provided with special oxygen inhalation equipment for his descent.

Boothby, Benson and Lovelace (12) have devised such an apparatus, which consists of a small cylinder of oxygen with accessory apparatus and mouthpiece. The emergency cylinder contains 34 liters of oxygen, which is sufficient to last ten to fifteen minutes and to maintain consciouness. In fact, it is sufficient, if the aviator is properly trained in its use, to maintain consciousness down to 10,000 feet or 15,000 feet, at which height he will, of course, be safe. The emergency cylinder can be carried in a specially constructed and strongly reinforced pocket in his parachute harness.

As the mask probably would be blown away during the act of jumping out of the plane, it is necessary to supply a mouthpiece with automatic sponge rubber valve which the aviator places in his mouth and grips with his teeth before jumping. This mouthpiece is held in place just below the chin by a rubber strap around the neck, so that the aviator can quickly place the mouthpiece in his mouth, grasp it firmly with his teeth, open the emergency cylinder valve, and jump. This procedure, about which it takes so long to tell, can be accomplished in a few seconds. Tests have been made with perfect ease from a simulated 40,000 feet, in a low pressure chamber, with descent at the calculated rate of a parachutist. As yet, tests have not been made in an actual jump from a plane at a high elevation.

Supercharged Cabin

The best method on commercial airlines compensating for the decrease in the partial pressure of oxygen at altitude is by use of the supercharged cabin airplane. This procedure is possible and practical, since the percentile composition of the air is essentially the same at very high altitudes as it is at sea level. By increasing the pressure of the air in the cabin of such an airplane, the partial pressure of oxygen is obviously raised to the desired level. By maintaining the pressure inside the cabin at or near ground level pressure, ear and sinus pain, as well as gaseous distress, is eliminated.

Transportation of Patients by Airplane

The airplane is continuing to be of more and more value not only for the conveyance of patients by air, but also for the transportation of doctors and medical supplies to the scene of disaster, particularly if there has been a major catastrophe, such as a tornado, flood, or earthquake.

Simpson, in 1929, advocated the more extensive use of airplane

ambulances in the army and emphasized greater speed and comfort in flight. These two factors, in many instances, would mean the saving of lives, and in addition there would be a decided conservation of medical personnel, since the work of the mobile surgical unit in the field would be considerably diminished. He assumed 4,000 casualties a day in an infantry brigade in a beginning offensive: 150 killed, 450 ambulatory, 200 requiring transportation in a sitting position, and 200 in a recumbent position. Of these 200, eighty were considered as "non-evacuable," but destined for a surgical hospital. If these eighty could be transported to a surgical hospital by litter and motor ambulance, they could then be transported by airplane directly to a general hospital, which would shorten materially the time required to bring casualties to their ultimate destination. When there is a landing field in the vicinity of a collecting station, these eighty patients could be flown to a general hospital in less time than would be required to transport them to a surgical hospital by motor ambulance. Three large airplanes similar to those now in use on commercial airlines, with distinctive markings, could easily carry these patients at one trip or one such airplane could carry them in three trips. Approximately thirty minutes of flying time would be required for a 100-mile flight of this nature.

Lieutenant General Hippke, Surgeon General of the German Air Force, discussed (1940) airplane evacuation of the sick and wounded from Poland to hospitals in Germany. A total of 2500 patients were evacuated in this manner, which, at this rate, would mean that 30,000 patients a year could be evacuated. Every airplane ambulance had an experienced medical officer aboard. Hippke advocated the use of commercial passenger planes on which the proper insignia could be painted and the necessary litter installations made.

Of the 2500 patients transported by air from Poland to Germany, only four died either in the airplane or immediately after landing. One patient had a gunshot wound of the lumbar vertebrae with retroperitoneal hemorrhage; two had pulmonary wounds and hemothorax, and the fourth had severe peritonitis.

On the return trip, medical supplies and medical personnel for replacement purposes could be carried, which would decrease the amount of material that would ordinarily be carried by trucks and would relieve the roads of much traffic. During the Polish campaign, medicine, serums, medical and surgical equipment, special dressings and special diets for dysentery patients in field hospitals were all transported to the front by airplane ambulances.

Airplane ambulances should be well heated, comfortable, as quiet as possible, have adjustable litters that could either be placed in the shock or head-up position, and carry suitable masks for the administration of oxygen. Simpson advocated the institution in flight of such emergency treatment as application or adjustment of splints, administration of stimulants and narcotics, the arrest of hemorrhage, and the treatment of shock, including the intravenous administration of fluids. Light weight sponge rubber mattresses

would be very comfortable for the patients. The litters should be so arranged that the patient could either be recumbent, in the shock position, or in the head-up position.

Beaven recommended (1935) the use of two types of airplane ambulances: a small or rescue type capable of landing and taking off in small emergency field, and a large or transport type of airplane for routine work. In addition to the large transport type of airplane ambulance, Hippke (1940) also advocated small planes with a low landing speed in regions where the roads are blocked and the motor ambulance has difficulty in reaching the loading points or where suitable landing fields are not available. This small type of shuttle plane is independent of the roads and can land close to every dressing station.

Beaven also felt that the transportation of patients by airplane ambulances would relieve the hospital station and evacuation hospitals of a large percentage of their load. Other advantages would be the ability to reach isolated army stations with highly trained personnel or to transport some patients to larger hospitals where they could be treated by specialists. Beaven also advocated the use of airplane ambulances during maneuvers and at air corps training schools.

The disadvantages of airplane ambulances are: necessity for reasonably good landing fields and servicing facilities, adverse weather, the need for trained pilots, and the danger of attack by enemy aircraft. In many instances, the airplane ambulances could be flown and serviced from regular army air fields. Very bad weather would force cancellation of flights. Civilian pilots with adequate training could relieve the army pilots. Stewardesses from the commercial airlines could be quicly trained in the care of wounded in flight. All trips would be behind the front lines and distinctive markings could be employed on the wings and fuselage of the planes. Night flights could also be made.

The advantages of transport of wounded by airplane are: unusual speed and comfort in transit instead of a rough and long ride in a motor ambulance; safety, conservation of medical personnel and field equipment, adequate treatment for the badly injured and seriously ill by shortening materially the period of time needed to bring them to their ultimate destination, thereby improving his chance of recovery, especially if a major surgical procedure is necessary. Morale would be higher than the average if a soldier knew such service was available.

Schmidt pointed out that in contradistinction to all transportation on land, the airplane maintains its speed without appreciable interruptions from take-off to landing. Wounded German soldiers felt very grateful for their transportation to their home bases for treatment and they maintained a high morale.

Air Commodore Glynn of the Royal Air Force considered (1940) the

airplane ambulance as a very valuable addition to the existing mechanical means of transport, that is, motor ambulances, ambulance trains, ambulance barges and hospital ships. However, the airplane is considered the most efficient means of transporting casualties that exist since only aircraft can convey patients vast distances over rough terrain to large, well equipped hospitals in the shortest possible time with a minimum of discomfort.

The advantages of judiciously employed airplane ambulances in Glynn's estimation are as follows: rapid evacuation of casualties from forward zone; quick transportation of seriously injured persons to a base hospital where specialists would be available; a more even distribution of patients to various base centers; decreased work of surgical teams in forward areas; decreased congestion on the lines of communication; maintenance of the morale of the patients since they would know that a completely equipped and adequately staffed hospital would be reached in a short time.

Hippke (1940) felt that it is of decisive importance that seriously wounded patients reach the operating surgeon promptly, and on the basis of personal observation stated that it is clear that air transportation is far less injurious to the patient than is ground evacuation, regardless of the time consumed in the movement. Other advantages stressed by Hippke are the actual speed and short duration of evacuation by air as well as the opportunity to have the patients constantly observed and cared for by trained personnel during flight.

An example given by Tonnis as to the effective support ambulance airplanes can render was in the case of a patient who had an abdominal wound with prolapse of the small intestine, incurred near Warsaw. He arrived on the operating table of the surgical clinic of the University of Breslau two and a half hours after the wound was received. It was emphasized that this is a record to which the patient owed his uneventful recovery. Ocular injuries, wounds of joints, and gunshot fractures and wounds of the lung were particularly benefited by airplane evacuation of patients to surgical clinics where the best personnel and diagnostic therapeutic equipment were available. In previous campaigns it was observed that patients with gunshot wounds of the lungs and severe fractures of the extremities did not tolerate well transportation by land.

The information required by the R.A.F. Headquarters, whose units will supply the aircraft, should include in Glynn's opinion the number of patients lying and sitting, to be evacuated, the site of the evacuating units, the desired time of arrival of the airplanes, and the destination. The medical authorities at the Base would be informed of the terminal airport, number of cases and condition of patients and expected time of arrival, to insure the availability of ambulances and hospital accommodation.

Major F. Schmidt, commander of an ambulance squadron in the German Air Force, advocated a strap to secure each litter in place to guard against sudden lurching of the plane caused by rough air, the smooth, rapid exchange of

empty for loaded litters, the grouping of several planes into a medical squadron, well ventilated and heated cabins, and the use of small communications airplanes to restore broken contacts quickly, receive new orders, and select satisfactory landing fields near the wounded.

Additional uses of aircraft listed by Glynn include the mobile surgical teams in the Royal Air Force which are maintained instantly available for dispatch by air to any airport where the number and severity of the casualties demand their services. The personnel of these teams includes a surgeon, an anesthetist, a theater sister, and two operating room assistants. The equipment in portable packs is completely self-contained and includes operating lights and a portable operating table. Within a few minutes after the plane has landed, operations of any nature can be undertaken. The total weight of the equipment is about 1120 pounds, which is contained in a space of approximately 50 cubic feet. Airplanes can also convey transfusion teams with apparatus and stored blood to any desired locality, as well as permit the teams to carry out transfusions in flight. In the case of isolated posts with no adjacent landing fields, medical supplies can be dropped by parachute.

It is now an accepted fact that the onset of anoxemia in a normal individual occurs at an altitude of 10,000 to 11,000 feet. It is seldom necessary to go higher in airplane ambulances. Since the amount of oxygen that is taken up by the hemoglobin and the plasma is directly dependent on the partial pressure of oxygen in the atmosphere and in the alveolar air, it is obvious that any clinical condition which causes anoxemia will be borne less well in high altitudes than at sea level. For example, at sea level the partial pressure of oxygen to which the alveoli of the lungs are exposed is calculated as follows: 760 mm. — 47 mm. x 20.93 per cent = 149 mm.; whereas at 10,000 feet it would be 523 mm. — 47 mm. x 20.93 per cent = 99.6 mm. instead of the normal sea level pressure of 149 mm. The percentile composition of the air is the same. Therefore, airplane ambulances should operate at as low an altitude as is safe and smooth not only to avoid anoxemia but also to prevent undue expansion of the gases in the gastrointestinal tract. Anoxemia would naturally occur at a much lower altitude in certain types of patients being transported by airplane ambulance, and for this reason it would be essential to have efficient oxygen masks available on the planes.

Schnedorf, Munslow, Crawford, and McClure demonstrated experimentally that concussion of the brain, with or without fracture of the skull, caused a depression of the arterial oxygen from 5 to 44 per cent below normal in dogs and patients. Oxygen therapy restored the oxygen of the blood saturation to and above normal and decreased the marked elevations of body temperature to normal. They concluded that oxygen therapy is indicated for the combating of anoxmia which results from injury of the head and for the amelioration of reactions which follow injury of the brain and mild anoxia. As a result of the demonstration of anoxia resulting from injury of the head at ground level, it would seem most advisable to administer oxygen to all patients with moderate to severe injuries of the head, who are being transported in airplane ambulances, in order to reduce the morbidity and mortality of head injury with an associated cerebral

injury.

Walsh [43] reported the following observation in the case of a woman aged thirty-five years who had undergone right temporal craniotomy for focal encephalitis and had recovered satisfactorily. The center of the scalp overlying the bony defect in the skull was, at times, depressed about 1.5 cm. below, and at other times it was elevated 0.5 cm. above the level of the skull. During ascent in a low pressure chamber, this subject inhaled a high concentration of oxygen. At a simulated altitude of 28,000 feet, corresponding to a barometric pressure of 247 mm. or about a third of an atmosphere, the scalp was elevated about 0.5 cm. above the level of the skull, from the original level of 0.5 cm. below the level of the skull. On descent to ground level, the scalp returned to the original level. This observation was considered by Walsh to indicate a change in volume of the intracranial contents, the exact cause of which was not determined. However, if the cranium had been intact, the intraspinal pressure, according to Walsh and Boothby, [44] would have shown an increase of approximately 3 cm. of spinal fluid in a manometer arm attached to a spinal puncture needle on ascent to 28,000 feet. Walsh and Boothby demonstrat air bubbles in a glass manometer attached to a spinal puncture needle introduce into the spinal canal of three men; in one case, bubble formation was observed in the spinal fluid in the ascending limb of the manometer at a height of 10,000 feet; in the second and third cases the formation was seen at 12,000 feet. The bubbles became larger and more numerous up to 28,000 feet; after a few minutes at this altitude they decreased in size and number and shortly disappeared.

Armstrong placed animals with trephined skulls in a low pressure chamber and observed the brain as the pressure was decreased. The brain began to expand at about 17,000 feet, and at 18,000 feet, or slightly above, definite expansion of the brain was observed.

Major W. Tonnis, consulting surgeon, office of the Surgeon General, Air Forces in Germany, found that all seriously wounded soldiers have suffered from more or less severe hemorrhage so that on the second or third days the concentration of hemoglobin may range between 35 and 53 per cent. In such cases, an altitude of approximately 4,000 feet was not exceeded unless oxygen was available. The breathing capacity was found to be reduced in cases of gunshot wounds of the lungs with hemothorax as well as in cases of gunshot wounds of the abdomen with a resultant elevated diaphragm resulting from distention or accumulation of fluid. Such patients suffered from definite respiratory distress at altitudes as low as 4,000 feet, but this could be relieved by the administration of oxygen.

In considering the transportation of anemic patients by airplane, it is important to remember that the arterial blood as it leaves the lung is normally saturated with oxygen in cases of anemia, but since there is a subnormal quantity of hemoglobin to unite with it, less oxygen can be carried. An anemic patient may not be cyanotic even if the saturation of arterial blood is as low as 60 per cent, because cyanosis is a direct result of reduced hemoglobin. Oxygen, preferably in high concentration, should be administered even at relatively low

altitudes in flight to patients with severe anemia as a prophylactic measure to forestall a failure in the normal compensatory mechanism.

Oxygen deficiency can be controlled by the administration of oxygen by a suitable mask such as the B.L.B. inhalation apparatus. Hippke advised the routine administration of oxygen to all patients at an altitude of above 11,500 feet. Oxygen deficiency certainly plays a role in cases of gunshot wounds of the lungs.

The best preventive measure in cases of airsickness, according to Hippke, is the recumbent position (shock position).

Pneumothorax. Lovelace and Hinshaw [31] have shown the hazards of aerial transportation to patients with pneumothorax. Boyle's law states that the volume occupied by a given quantity of gas is inversely proportional to the absolute pressure exerted on it. It is obvious that this law would apply to the pneumothorax if the impounded air is enclosed in a pocket with adequately flexible walls. A progressive decrease in atmospheric pressure produced by ascent will thus tend to increase pulmonary collapse in cases of therapeutic, spontaneous or traumatic pneumothorax. The volume occupied by a pneumothorax should be doubled by ascent from sea level to an altitude of slightly more than 15,000 feet (table 4, p. 306)Even an altitude of only 10,000 feet should cause considerable increase (1.5 times) in the volume of a pneumothorax.

The hazards of large and rapid increases in pulmonary collapse are well known. Pleural adhesions, if present, may be subjected to sufficient tension to produce rupture, and if tuberculous tissue is thus exposed, tuberculous empyema could occur with disastrous results. Even in the absence of adhesions, a large pneumothorax can cause sufficient compression to embarrass respiration seriously.

Demonstration of increased volume of a pneumothorax during simulated altitude ascent in a low pressure chamber was recently carried out by means of roentgenograms of the thorax taken at various altitudes up to 12,000 feet. This increased collapse was found to be very striking.

The steadily increasing popularity of airplane transportation makes it urgent that physicians be warned of its special dangers to these patients. Those with pleural adhesions, those with a pneumothorax of large volume and those whose pneumothorax has recently been refilled are in greater danger.

Willcox and Foster-Carter (1937) reported a case in which spontaneous pneumothorax occurred, during flight, in a pilot who had an associated bullous emphysema as proved by roentgenograms and necropsy.

Gas in gastro-intestinal tract. Just as in the case of expansion of the air in a pneumothorax, gas normally present in the gastro-intestinal tract will expand with altitude, according to the corresponding change in

atmospheric pressure (table 4). Ordinarily, relief is obtained by belching and passing flatus. If patients who have penetrating wounds of the stomach or intestine are being transported by airplane, the expansion of gas would be a serious problem, inasmuch as the gas would be forced out through the openings in the intestine and carry fecal material with it and materially increase the danger from peritonitis. The leakage of gas would probably not occur at very low altitudes, but the only way to prevent it at high altitudes would be by the use of a pressure cabin type of airplane in which the pressure inside the cabin would be maintained at or near ground level. Armstrong has pointed out that patients with strangulated hernia or intestinal obstruction should not be exposed to high altitude for this reason.

Shock. Severe shock was considered by Hippke to be an absolute contraindication to transport by airplane ambulance. It is believed this contraindication refers to secondary or wound shock which is a condition of circulatory failure, caused by diminished blood volume, with a consequent fall in cardiac output and blood flow through the tissues of the body. Contributory factors to the development of such shock, aside from hemorrhage, are fatigue, dehydration, exposure to cold, and pain. When a patient in shock would have to be transported by airplane ambulance because of approaching enemy troops, it would be well to heed the advice of the Germans and administer 1,000 to 2,000 cc. of blood in order to restore a relatively normal blood volume, which will often prevent irreversible damage to blood vessels and to the central nervous system.

As brought out in the British [36] report on shock, from a practical aspect and with wounds of war, the usual dehydration of a wounded man tends to inhibit compensatory blood dilution from hemorrhage, while the amount of tissue injury encourages loss of plasma. If signs of shock are present, particularly pallor and a pulse rate greater than 110, treatment should be instituted without delay, even though the systolic blood pressure is more than 100 mm. of mercury. As stressed in this report, if the blood pressure is more than 100 mm. of mercury, the condition is partially compensated, but the arterial pressure is being maintained only by intense vasoconstriction and is likely to fall with the slightest intensification of shock, as, for example, as a result of anesthesia or a small loss of blood or plasma, or anoxemia.

Procedures employed for the treatment of shock in the resuscitation wards in England include: complete rest in a quiet and comfortable shelter; warm clothes and external application of heat; morphine for the relief of pain; arrest of hemorrhage and loss of plasma by a properly applied tourniquet or pressure bandage; transfusion to restore blood volume; administration of fluids, and the administration of oxygen in high concentration with the B.L.B. inhalation apparatus or other suitable equipment which tends to relieve tissue anoxia and may bring about considerable improvement in case of shock.

Infection. In the presence of fulminating infection of any kind, even if the infection itself is uninfluenced, the circulatory collapse

associated with peritonitis, septicemia, and similar conditions can be relieved partially, at least, by the administration of high concentrations of oxygen. Oxygen is particularly indicated to prevent or decrease the additional anoxia and other secondary reactions which often accompany the administration of sulfanilamide or similar drugs.

Hyperthyroidism. In cases of hyperthyroidism, anoxemia may develop easily and frequently may lead to serious consequence because of the relatively increased consumption of oxygen, as evidenced by an elevated basal metabolic rate.

Table 1

National Advisory Committee for Aeronautics
Report No. 538
Altitude-pressure tables based on the United States standard atmosphere (1935)
Altitude-pressure-temperature table
(To which is added the equivalent oxygen per cent)*

Altitude, feet	Pressure in. Hg	Pressure mm. Hg	Temp. °C.	Mean Temp. °C.	Equiv. oxygen, per cent
0	29.921	760.0	15.0	15.0	20.93
500	29.38	746.4	14.0	14.5	20.56
1,000	28.86	732.9	13.0	14.0	20.18
1,500	28.33	719.7	12.0	13.5	19.82
2,000	27.82	706.6	11.0	13.0	19.46
2,500	27.31	693.8	10.0	12.5	19.11
3,000	26.81	681.1	9.1	12.0	18.76
3,500	26.32	668.6	8.1	11.5	18.41
4,000	25.84	656.3	7.1	11.0	18.07
4,500	25.36	644.2	6.1	10.5	17.74
5,000	24.89	632.3	5.1	10.0	17.41
5,500	24.43	620.6	4.1	9.5	17.09
6,000	23.98	609.0	3.1	9.0	16.77
6,500	23.53	597.6	2.1	8.5	16.46
7,000	23.09	586.4	1.1	8.0	16.15
7,500	22.65	575.3	0.1	7.5	15.84
8,000	22.22	564.4	-0.8	7.0	15.54
8,500	21.80	553.7	-1.8	6.5	15.25
9,000	21.38	543.2	-2.8	6.0	14.96
9,500	20.98	532.8	-3.8	5.5	14.67
10,000	20.58	522.6	-4.8	5.0	14.39
10,500	20.18	512.5	-5.8	4.5	14.11
11,000	19.79	502.6	-6.8	4.0	13.84
11,500	19.40	492.8	-7.8	3.5	13.57
12,000	19.03	483.3	-8.8	2.9	13.31
12,500	18.65	473.8	-9.8	2.4	13.05
13,000	18.29	464.5	-10.8	1.9	12.79

13,500	17.93	455.4	-11.7	1.4	12.54
14,000	17.57	446.4	-12.7	0.9	12.29
14,500	17.22	437.5	-13.7	0.4	12.05
15,000	16.88	428.8	-14.7	-0.1	11.81
15,500	16.54	420.2	-15.7	-0.6	11.57
16,000	16.21	411.8	-16.7	-1.2	11.34
16,500	15.89	403.5	-17.7	-1.7	11.11
17,000	15.56	395.3	-18.7	-2.2	10.89
17,500	15.25	387.3	-19.7	-2.7	10.67
18,000	14.94	379.4	-20.7	-3.2	10.45
18,500	14.63	371.7	-21.7	-3.7	10.24
19,000	14.33	364.0	-22.6	-4.3	10.02
19,500	14.04	356.5	-23.6	-4.8	9.82
20,000	13.75	349.1	-24.6	-5.3	9.61
20,500	13.46	341.9	-25.6	-5.8	9.42
21,000	13.18	334.7	-26.6	-6.3	9.22
21,500	12.90	327.7	-27.6	-6.9	9.02
22,000	12.63	320.8	-28.6	-7.4	8.83
22,500	12.36	314.1	-29.6	-7.9	8.65
23,000	12.10	307.4	-30.6	-8.4	8.47
23,500	11.84	300.9	-31.6	-9.0	8.20
24,000	11.59	294.4	-32.5	-9.5	8.11
24,500	11.34	288.1	-33.5	-10.0	7.93
25,000	11.10	281.9	-34.5	-10.5	7.76
25,500	10.86	275.8	-35.5	-11.1	7.60
26,000	10.62	269.8	-36.5	-11.6	7.43
26,500	10.39	263.9	-37.5	-12.1	7.27
27,000	10.16	258.1	-38.5	-12.7	7.11
27,500	9.94	252.5	-39.5	-13.2	6.95
28,000	9.72	246.9	-40.5	-13.7	6.80
28,500	9.50	241.4	-41.5	-14.3	6.65
29,000	9.29	236.0	-42.5	-14.8	6.50
29,500	9.08	230.7	-43.4	-15.3	6.35
30,000	8.88	225.6	-44.4	-15.9	6.21
30,500	8.68	220.5	-45.4	-16.4	6.07
31,000	8.48	215.5	-46.4	-16.9	5.93
31,500	8.29	210.6	-47.4	-17.5	5.80
32,000	8.10	205.8	-48.4	-18.0	5.67
32,500	7.91	201.0	-49.4	-18.6	5.54
33,000	7.73	196.4	-50.4	-19.1	5.41
33,500	7.55	191.8	-51.4	-19.6	5.28
34,000	7.38	187.4	-52.4	-20.2	5.16
34,500	7.20	183.0	-53.4	-20.7	5.04

35,000	7.04	178.7	-54.3	-21.3	4.92
35,332	6.93	175.9	-55.0	-21.6	4.84
35,500	6.87	174.5	-55.0	-21.8	4.81
36,000	6.71	170.4	-55.0	-22.3	4.69
36,500	6.55	166.4	-55.0	-22.8	4.58
37,000	6.39	162.4	-55.0	-23.3	4.47
37,500	6.24	158.6	-55.0	-23.8	4.37
38,000	6.10	154.9	-55.0	-24.3	4.27
38,500	5.95	151.2	-55.0	-24.8	4.16
39,000	5.81	147.6	-55.0	-25.2	4.06
39,500	5.68	144.1	-55.0	-25.6	3.97
40,000	5.54	140.7	-55.0	-26.0	3.87
40,500	5.41	137.4	-55.0	-26.4	3.78
41,000	5.28	134.2	-55.0	-26.8	3.70
41,500	5.16	131.0	-55.0	-27.2	3.61
42,000	5.04	127.9	-55.0	-27.6	3.52
# 43,000	4.80	122.0	-55.0	-28.3	3.36
43,500	4.69	119.1	-55.0	-28.6	3.28
44,000	4.58	116.3	-55.0	-29.0	3.20
44,500	4.47	113.5	-55.0	-29.3	3.13
45,000	4.36	110.8	-55.0	-29.6	3.05
45,500	4.26	108.2	-55.0	-29.9	2.98
50,000	3.44	87.3	-55.0	-32.4	2.37
60,000	2.13	54.2	-55.0		1.49
70,000	1.32	33.6	-55.0		0.93

*Example: Oxygen per cent = 20.93/760 x barometric pressure at that level.

#42,500	4.92	124.9	-55.0	-28.0	3.44

Table 2

Normal gas pressures*

Location	O_2 Pressure		CO_2 Pressure	
	Per cent atmosphere	mm. of mercury	Per cent atmosphere	mm. of mercury
Inspired air	20.93	159	0.03	0.2
Lung alveoli	14.00	106	5.5	40
Arterial blood	13.21	100	5.5	40
Venous blood	5.50	40	6.2	46
Tissue spaces	3--5.50	20--40	6.2--8.5	46--60

*From Campbell, Argyll and Pulton, E. P.; Oxygen and carbon dioxide therapy. London, Oxford University Press, 1934, 179 pp.

Table 3

Oxygen flow needed for B.L.B. oxygen inhalation apparatus. Rates of oxygen flow needed by aviators at various elevations with different degrees of activity when wearing the B.L.B. inhalation apparatus are indicated.

Actual elevation (thousand feet)	Aviator, inactive Set oxygen flowmeter to correspond to actual elevation		Aviator, active Set* oxygen flowmeter to correspond to 5,000 feet above actual elevation		Aviator, very active Set* oxygen flowmeter to correspond to 8,000 feet above actual elevation	
	Liters per min.		Liters per min.		Liters per min.	
	S.T.P.D.	In body	S.T.P.D.	In body	S.T.P.D.	In body
(C to) to 10	0.5	0.9	0.8	1.5	1.0	1.8
11 to 15	0.7	1.6	1.2	2.7	1.4	3.2
16 to 20	1.0	2.9	1.6	4.6	1.8	5.2
21 to 25	1.3	4.8	2.0	7.4	2.2	8.1
26 to 30	1.7	8.3	2.4	11.7	2.6	12.7
27 to 35	2.1	13.8	2.7	17.8	2.9	19.7
36 to 40	2.4	22.1	Dangerous		Dangerous	

(1) "Inactive" - By this is meant that the pilot is sitting in his seat and flying the plane under ordinary atmospheric conditions corresponding approximately to an oxygen consumption of 250 to 300 cc. per minute S.T.P.D.

(2) "Active" - By this is meant as strenuous an amount of work as a pilot handling the plane in emergencies or a machine gunner actively firing corresponding approximately to an oxygen consumption of 400 to 500 cc. per minute S.T.P.D.

(3) "Very active" - By this is meant as strenuous an amount of work as can be performed in an airplane corresponding approximately to an oxygen consumption of 500 to 600 cc. per minute S.T.P.D., which is about the equivalent of walking at the rate of 2 miles per hour.

*This setting refers to the Heidbrink type of kinetic flowmeter that has been calibrated according to the recommendations of Boothby and Lovelace. At these settings the actual amount delivered corresponds to the amount in the table.

In the calibration of other types of flowmeters, these rates of flow should be conveniently indicated.

The columns under "Liters per min." headed "In body" indicate the volume of the oxygen after it has expanded to the condition in the lungs at body temperature (37° C.), saturated with moisture (47 mm.), and at the barometric pressure corresponding to actual elevation.

Table 4

Comparative volumes of gases (saturated at 37° C.*) inside the body at various altitudes

Barometric pressure mm., mercury	Altitude feet	Relative vols. of gas
760	0	1.0
523	10,000	1.5
429	15,000	1.9
349	20,000	2.4
282	25,000	3.0
226	30,000	4.0
179	35,000	5.4
141	40,000	7.6

*Pressure of aqueous vapor at 37° C. is 47 mm. of mercury. Example of calculation $\frac{760-47}{523-47} = 1.5$

References

1. Armstrong, H. G.: Principles and practice of aviation medicine. Baltimore, Williams & Wilkins Company, 1939, 496 pp.

2. Armstrong, H. G. and Heim, J. W.: The effect of repeated daily exposures to anoxemia. J. Aviation Med. 9:92-96 (June) 1938.

3. Barach, A. L.: "Pilot error" and oxygen want; with a description of a new oxygen face tent. J.A.M.A. 108:1868-1872 (May 29) 1937.

4. Barach, A. L., McFarland, R. A., and Seitz, C. P.: The effects of oxygen deprivation on complex mental functions. J. Aviation Med. 8:197-207 (Dec.) 1937.

5. Beaven, C. L.: The present need for airplane ambulances by the United States. Mil. Surgeon. 77:138-146 (Sept.) 1935.

6. Benson, O. O., Jr.: Coronary artery disease; report of fatal cardiac attack in a pilot while flying. J. Aviation Med. 8:81-84 (June) 1937.

7. Benson, O. O., Jr.: The effect of decreased barometric pressure on the electrocardiogram. J. Aviation Med. 11:67-74 (June) 1940.

8. Bert, Paul: La pression barométrique; recherches de physiologie expérimentale. Paris, G. Masson, 1878, 1168 pp.

9. Bohr, Christian: Absorptions coefficienten des Blutes und des Blutplasma fur Gase. Skandinav. Arch. f. Physiol. 17:104-112, 1905.

10. Bohr, C., Hasselbalch, K. and Krogh, August: Ueber einen in biologischer Beziehung wichtigen Einfluss, den die Kohlensaurespannung des Blutes auf dessen Sauerstoffbindung ubt. Skandinav. Arch. f. Physiol. 16:402-412, 1904.

11. Boothby, W. M.: Oxygen administration: the value of high concentration of oxygen for therapy. Proc. Staff Meet., Mayo Clin. 13:641-646 (Oct. 12) 1938.

12. Boothby, W. M., Benson, O. O. and Lovelace, W. R., II: Emergency oxygen unit for use in parachute escape or in case of failure of regular oxygen supply at high altitude. J. Aviation Med. 11:59-66 (June) 1940

13. Boothby, W. M., Lovelace, W. R., II and Benson, O. O.: High altitude and its effect on the human body. J. Aeronaut. Sc. 7:461-469 (Sept.); 1-7 (Oct.) 1940.

MAYO AERO MEDICAL UNIT

Walter M. Boothby, M. D., Chairman

A LABORATORY AID

Compiled for the most part by the various
ARMY and NAVY OFFICERS and MAYO FOUNDATION FELLOWS
who have been assigned to the Unit.

SECOND EDITION - AUGUST 1942

PREFACE TO FIRST EDITION

The contents are not wholly the work of the authors as some parts are taken from various articles on the subjects. It is not meant to be put into circulation, but rather as an aid for local use to clarify subjects and methods used and taught in this laboratory.

Most of the work was compiled from personal laboratory notes of the authors. It should enable future students to avoid voluminous note taking and thus devote more time to attentive absorption of knowledge with more time for practical work.

For those students who will be stationed at Aviation Medicine Laboratories in the future, it is our hope that these notes will prove to be of aid.

Captain M. Robert Halbouty, M.C., U. S. Army

Captain Joseph A. Resch, M.C., U. S. Army

Lieutenant Robert F. Rushmer, M.C., U.S. Army

January 1942

PREFACE TO SECOND EDITION

Since the first edition additional experimental methods and various new calculations are being utilized in the laboratory and these have been incorporated in the Manual. Practically none of the methods described are new although some of them have been modified specifically for high altitude problems. To conserve time in our war effort we have unceremoniously "lifted" charts and pictures from various sources. Unfortunately in several instances we find that we failed to give proper credit; this omission will be corrected in our next edition.

Mayo Aero Medical Unit

September 1942

RESPIRATION - DEFINITION OF TERMS

1. Tidal Air is the volume of air breathed in or out of the lungs with every normal respiration. Since this volume is proportional to the activity, it varies greatly under normal non-basal conditions. However, unless specified to the contrary, a resting sitting condition is assumed.

2. Complementary Air is the volume of air that can be inspired by maximum effort; the base line for this measurement is usually taken from the bottom of a normal resting expiration.

3. Reserve Air (supplemental air) is the maximum volume of air that can be expired as measured from the base line of a normal resting expiration.

4. Vital Capacity is determined by measuring the maximum quantity of air that can be expired after a maximal inspiration.

5. Residual Air is the air which remains in the lungs following a maximal expiration. It can only be expelled by opening the chest widely and allowing the lungs to collapse.

6. Functional Residual Air as measured by the method of Cournand[1] et al., includes both the reserve air and true residual air; therefore to calculate the true residual air one must determine the reserve air and subtract this from the value obtained for the functional residual air.

7. Total Lung Volume is the sum of the residual air and the vital capacity.

8. Dead Space Air is that portion of the inspired air which fills the respiratory passageways but does not take part in the respiratory change.

9. Alveolar Air is that portion of the inspired air which comes into gaseous and temperature equilibrium with the arterial blood of the alveolar walls; it contains therefore, 47 mm. of water vapor because it is completely saturated at the body temperature of 37° C. (see section on alveolar air for method of collection).

10. Tracheal Air is an arbitrary term used to designate the inspired air just as it enters the lungs and before any gaseous exchange has taken place but after it has been warmed to 37° C. (body temperature) and saturated with 47 mm. water vapor; aside from its added water vapor, the composition of the gases in the tracheal air is assumed for convenience of expression and calculation to be the same as in the air outside the body.

11. Respiratory Quotient is the ratio of the volume of carbon dioxide evolved to the volume of oxygen absorbed and depends on the character of the food being metabolized. Both volumes to obtain the exact ratio must be corrected for any change in volume of the expired air from the volume of the inspired air, although when breathing normal air the correction for carbon dioxide is so small that it can be neglected. When the R.Q. is not corrected for change in volume, it is sometimes referred to as the uncorrected R.Q.

---

1. Cournand, Baldwin, Darling and Richarez: J. Clin. Invest. 20:681 (1941)

Note embracing definitions 1 to 8 inclusive: The volume in most instances that is desired is the actual volume of the space occupied by the air. Therefore to determine this space by gasometric methods, one must express the gas volume at 37° C. and saturated with water vapor. While at sea level comparatively little error is produced by expressing this volume at the temperature and with the water vapor corresponding to the temperature of the measuring apparatus, yet at high altitudes such a careless method results in large errors.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

12. Alveolar Ratio is the quotient derived by dividing the percentage of carbon dioxide in the alveolar air by the difference between the percentage of oxygen in the inspired air (20.93 per cent when breathing normal air) and the percentage of oxygen in the alveolar air. It is essentially the "uncorrected respiratory quotient."

13. Hyperventilation or Hyperpnoea is excessive breathing: respiration at a rate or depth or both which results in the washing out of carbon dioxide from the alveolar air and the blood stream. Regardless of whether it occurs voluntarily or involuntarily from fright or hysteria, it results in profound physiological reactions and is used therefore in contrast to "increased ventilation" which is due to the normal needs of the body such as in exercise.

14. Acapnia is the condition resulting from hyperventilation in which excessive amounts of carbon dioxide have been eliminated from the blood.

15. Apnoea is the cessation of the respiratory movements and usually refers to that type caused by a reduction of the blood carbon dioxide to a concentration which no longer stimulates the respiratory center.

16. Dyspnoea is difficult breathing and may refer to either "obstructive dyspnoea" due to interference with the passage of air or to subjective dyspnoea in which one becomes conscious of definite discomfort in the effort to breathe.

17. Periodic breathing is an alternation of respiratory movements with periods of apnoea. It may follow or accompany hyperventilation. The term Cheyne-Stokes breathing is generally used with the same meaning as periodic breathing although the condition described by Drs. Cheyne and Stokes was limited to a clinical form of periodic breathing associated with pathological central nervous system changes.

18. Anoxia is a term introduced by Peters and Van Slyke to describe a generalized oxygen deficiency throughout the tissues of the body and refers to a decrease in the partial pressure of oxygen in the tissues which may or may not be associated with a decrease in partial pressure or in the percentage saturation of the hemoglobin of the arterial blood.

19. Anoxemia is, strictly speaking, an oxygen lack in the blood and usually refers to incomplete saturation of the hemoglobin in the arterial blood.

20. Cyanosis is a bluish color of the blood causing a corresponding change in the color of the skin, mucuous membranes or deeper organs. It depends upon the absolute amount of reduced hemoglobin in the blood and if present is, in normal individuals, an indication of both anoxia and anoxemia, but if absent does not necessarily mean that anoxia is present.

[illegible] is the [illegible] obtained by dividing the percentage of [illegible] by the difference between the percentage of oxygen in the inspired air [illegible] and the percentage of oxygen in the alveolar air. It is essentially the "instrumental respiratory quotient".

11. [illegible] is excessive breathing [illegible] washing out of carbon dioxide from the alveolar air and the blood stream. [illegible] voluntarily or involuntarily [illegible] it results in profound physiological reactions and is [illegible] in contrast to "[illegible]" which is due to the normal needs of the body such as in exercise.

[illegible] is the condition resulting from hyperventilation, in which excessive amounts of carbon dioxide have been eliminated from the blood.

[illegible] is the [illegible] of the respiratory movements and usually refers to the [illegible] caused by a reduction of the blood carbon dioxide due to a hyperventilation which [illegible] the respiratory centers.

[illegible] is difficult breathing and may refer to [illegible] breathing [illegible]

[illegible] breathing is an alternation of respiratory movements with periods of apnea. [illegible] The term [illegible] Cheyne and Stokes [illegible] a clinical type [illegible] pathological central nervous system changes.

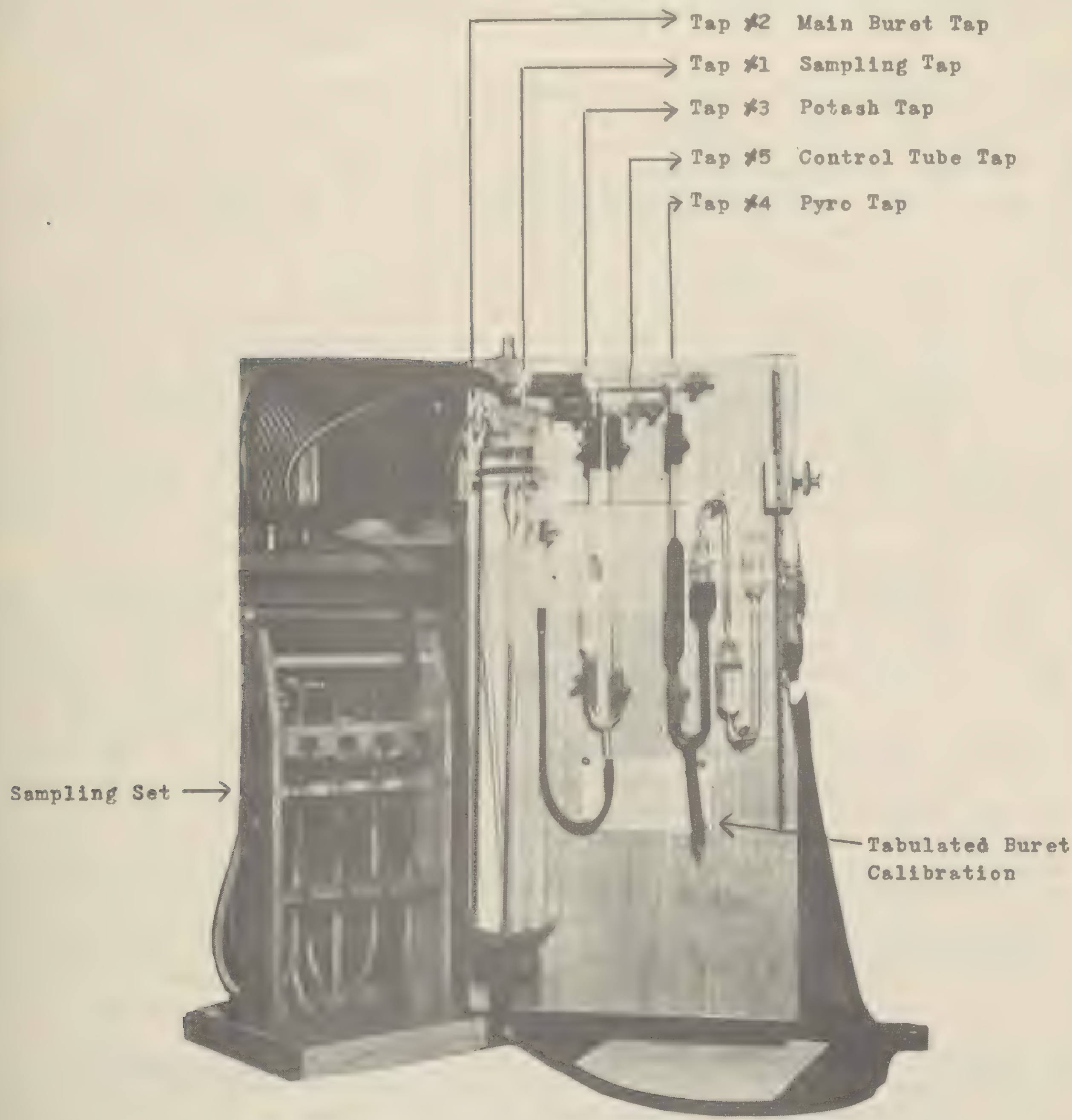
[illegible] is a term [illegible] by Barcroft and Van Slyke to describe a [illegible] a decrease in the [illegible] pressure of oxygen [illegible] the percentage saturation of the hemoglobin [illegible]

[illegible] oxygen lack in the blood and usually refers to [illegible] of the arterial blood.

[illegible] of the blood [illegible]

THE MOST CONVENIENT BURET IS ONE HAVING A BULB CAPACITY

OF 6 CC WITH THE GRADUATED STEM RUNNING FROM 6.0 to 10,1 CC



H A L D A N E

GAS ANALYSIS APPARATUS

THE HALDANE GAS ANALYSIS APPARATUS

The analyses are done in a Haldane gas analysis apparatus, described very fully by Haldane in his book on Air Analysis. Briefly, a sample of air is taken into the buret and its volume measured; the air is passed back and forth into the tube containing potash solution to absorb the carbon dioxide and then a second reading of the volume contraction made. The contraction in volume of the sample, due to absorption of carbon dioxide present by the potash solution, divided by the original volume of the sample is the percentage of carbon dioxide present in the dry sample of air. In like manner the percentage of oxygen is determined by absorbing the oxygen in potassium pyrogallate solution and measuring the contraction in the volume of the air sample.

The general arrangement of the apparatus is shown in the labeled illustration. It consists of a calibrated buret (A) of 10 cc. volume, a control tube (B) of approximately the same volume as the buret, both surrounded by a water-bath (c), and two absorption pipets of about 30 cc. capacity, the one containing potash (X) for carbon dioxide absorption and the other potassium pyrogallate (Z) for oxygen consumption. In addition, there are three three-way taps (1), (3), and (4) to connect the various parts of the apparatus, and there is also one diagonal tap (2) and one two-way tap (5). On all the taps a red spot or other mark is put on the handle to indicate the position of the arms. This mark if not on, can be improvised by putting a drop of colored sealing wax on the side where the 3rd hole is; that is, the bottom of the "T" on 3-way taps. All of the taps must be air-tight, fitting the bore perfectly, so that they turn without binding or making striations. Finally, there are the potash (P) and mercury (Q) reservoirs and beyond the pyro tube a seal tube (D) partly filled with dilute potash soluti on to prevent the pyro from coming in contact with the room air. The various parts of the Haldane are shipped dismounted and the buret has an extra tap fused in it to facilitate the calibration.

The standard sampling tubes for ground studies have a volume of 40 to 50 cc. with a two-way tap and small bored tip about 4 cm. long above the tap for the purpose of making connections with the collecting apparatus in sampling. Sufficient mercury is used in the sampling tube to completely fill it and the rubber tube leading to the mercury reservoir. In high altitude studies very large sampling tubes must be used of approximately 200 cc. capacity. A piece of rubber tubing about 15 inches long connects the standard sampling tube to its mercury reservoir of about 40 cc. capacity. The mercury reservoir of the high altitude sampling tube is about 200 cc. capacity. The standard sampling tubes are mounted in fours on a rack, and four samples of expired air are taken whenever possible; two are analyzed, and this leaves two extra samples in case of accident. The big tubes are mounted in pairs for high altitude analysis. The sampling tubes are filled to the tip with mercury. In sampling, connection is made to the petcock of the apparatus by means of rubber tubing. The tubing is tightly adjusted on to the sampling tube, the mercury reservoir lowered, and the tap on the sampling tube opened. The sample is collected, the tap is closed, and the mercury reservoir hung up to keep the sample under positive pressure.

Calibration of the Haldane Buret: To obtain accuracy in gas analysis it is necessary to calibrate the buret carefully. A frequent source of error when the T type of buret tap is used is that the glass maker may not properly take into consideration the volume of the openings in the tap. Then too, there may be the assumption that the buret has an absolutely even bore or the calibration may be improperly carried out with the buret upside down, etc.

A special calibration with fine point should be fused on the bottom of the buret. If this is impossible, the connection may be made with heavy rubber tubing

[illegible]

The specimens are then put in a [illegible] and analysis [illegible], determined [illegible] by [illegible] in the [illegible]. [illegible] volume of [illegible] in the [illegible] percentage of [illegible] in [illegible].

a. [illegible] the [illegible] of the [illegible] of [illegible] in the [illegible] and [illegible] the [illegible].

[illegible] sampling [illegible] the ground [illegible] a volume of [illegible] the [illegible].

[illegible]

[illegible]

around which adhesive tape is wound; this is necessary, otherwise the bulging of the rubber connections when the buret is full of mercury will gradually decrease as the mercury is drawn out for weighing and thus cause an error in calculated volume. In calibration, the buret is filled with dry clean mercury and the weights of the mercury corresponding to various volumetric readings on the buret are determined. Since the volume (V) of a liquid is equal to its weight (W) divided by its density (D) the corresponding volumes of the various weights of mercury are determined in decimal parts of the volume corresponding to the 10cc. mark. The volume of the mercury thus calculated is compared with the corresponding volumetric readings on the buret and the correction determined. If the temperature is kept within plus or minus 0.5°C., then the calibration will have corrections for decimal parts of the total (10 cc.) and therefore it is not necessary to transform these into exact cubic centimeters.

The buret is first thoroughly cleaned with warm cleaning solution, then rinsed with distilled water, and completely dried by sucking clean air through it. Do not blow air through from an air pump as that will contain a very fine oil spray even if the pump is far away. The clean, dry buret is filled through the calibration tap with mercury and up through the buret tap and just over the curved right angle. A convenient way of doing this is by suction or by attaching rubber tubing with a mercury reservoir to the lower end of the buret. It is important that no air bubbles are caught by the mercury. The calibration and the buret taps must never be left closed with the buret filled with mercury because the expansion of the mercury with the rise of room temperature will burst the buret. Instead, immediately cut off the head of the mercury column by turning the tap and completely removing the tap from its bore being careful not to spill any mercury. Then the mercury is run slowly down, approximately to the reading 6.0 cm. and is collected in a dry and clean, weighed dish. After gently tapping the buret with a pencil, the accurate reading of the volume of mercury in the buret to 0.001 cc. is recorded and the total weight to the nearest 0.001 gm. of mercury and dish found. Care should be taken that no particles of mercury cling to the inside of the buret and the mercury runs out. This usually means that the buret is greasy and should be recleaned. Touch the surface of the mercury in the dish to the mercury in the end of the calibration tap, so that a constant amount of mercury is left in the end of the buret after each portion of mercury is collected. The weighing should be done on a fine chemical balance and recorded to the nearest 0.001 gm.

To obtain correct readings the buret must be set up during the calibration so that it is perpendicular and the complete calibration carried out at one sitting without interruption. Before cutting off the head of the mercury wait until the mercury has had time to reach temperature equilibrium and be sure that the room temperature does not vary by more than 0.5°C, a thermometer should be hung near the buret and the temperature noted at each weighing and reading of the buret. Variations in the temperature affect the buret readings, a fluctuation of one degree causing a change in the volume 7 cc. of mercury of approximately 0.001 cc. The room in which the calibration is b eing carried out should, therefore, be kept at as constant a temperature as possible and drafts avoided. Likewise, care must be taken not to breathe on the buret or to touch it with the hands during the calibration. The buret should be gently tapped with a pencil before the reading is taken to obtain a true meniscus of the mercury. The reading lens should be held parallel with the buret with the center of the lens opposite the mercury meniscus. The eyes must be on the correct level before making a reading of the mercury meniscus. To do this the reflections on the mercury of the two 0.01 cc. markings on the buret just below the mercury meniscus are located and the eyes are on the correct level when these two lines and their reflections on the mercury exactly coincide.

[illegible]

[illegible]

[illegible]

[illegible]

The weights of successive portions of the mercury are found for various readings of the buret approximately at 6.0, 6.3, 6.5, 7.0, 7.3, 7.5, 8.0, 9.0, 9.3, 9.5, 9.8, and 10cc. The calibration is then repeated, without cleaning the buret, determining the weight of mercury at the reading, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5 and 10. It is preferable to do the two calibrations at one sitting and the corrections should check within plus or minus 0.001 cc.

Instead of using the absolute density of the mercury corresponding to the temperature recorded by the thermometer near the buret, we calculate the comparative density of the mercury from the experimental data. In calibrating buret number 29 at the reading 10.000 cc. the weight of the mercury was 135.1704 gm., its density is therefore $\frac{135.1704 \text{ gm.}}{10.000 \text{ cc.}} = 13.51704$. The true volume of 6.000 cc. with mercury for this reading weighing 81.1144 gm. is obtained by dividing by 13.51704 and equal to 6.001. That is, the buret at 6.001 cc. - 6.000 cc. = + 0.001 cc. When the corrections for the various readings are determined as above they are plotted on graph paper and the plus or minus corrections for each 0.1 cc. reading of the buret are read off from the curve and listed for use.

As noted before, the calibration tap should be fused to the buret and not attached by rubber tubing, because changes in level of the mercury from the top to the bottom of the buret will produce variations in pressure against the rubber tubing, and consequently the latter will not always have the same bore, and an appreciable error in the calibration results.

Calibration Example

Temp.	Reading	Wt. of Hg.		Volume Hg in Stem
27.1	6.000	Wt. of container plus Hg	89.2286	$\frac{\text{Wt. Hg in stem } 81.114}{\text{Density Hg } 13.51704} = 6.001 = +.001$
		Wt. of container	8.1142	
			81.1144	

Solutions for Haldane Gas Analysis: Potassium pyrogallate solution (Haldane): to 650 gms of stick potassium hydroxide (not purified by alcohol as vapor will always be present and cause errors) are added 300 cc. of distilled water. The specific gravity of the resulting solution should be exactly 1.55 (this can be determined by using a hydrometer or by finding the weight of 100 cc. of the solution, which should be 155 gm.). If the specific gravity is too low, potassium hydroxide should be added until the desired concentration is obtained. To 100 cc. of this concentrated potash solution 10 gm. of Merck's pyrogallic acid are added in a bottle with a greased glass stopper. Haldane emphasizes that the solution must be made exactly in the manner described otherwise unsatisfactory results are obtained. The resulting solution of potassium pyrogallate should have a brownish-green tint and should become a deep wine color immediately on exposure to air. The pyro should be at least a month old before using, although it improves with age. This again can sometimes be hastened by exposing the pyro for a few minutes to air and thus giving it a start.

Potash solution for CO_2 absorption: For the absorption of carbon dioxide we use a dilute solution of potassium hydroxide of specific gravity of about 1.09 - approximately a 10 per cent solution.

After 50 standard Haldane analyses or 25 high oxygen concentration analyses in the Haldane apparatus solutions in the Haldane apparatus should be changed.

The weights of successive portions of the mercury are found for various [illegible] of the buret approximately at 6.0, 6.3, 6.5, 7.0, 7.3, 7.5, 8.0, 9.0, 9.3, [illegible] and 10.0. [illegible] determining the weight of mercury at the reading, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5 and 10. It is permissible to do the two calibrations at one sitting and the corrections should check within plus or minus 0.001 cc.

Instead of using the absolute density of the mercury corresponding to the temperature recorded by the thermometer near the buret, we calculate the comparative density of the mercury from the experimental data. In calibrating buret [illegible] at the reading [illegible] cc. the weight of the mercury was 13[illegible] gm., its density is therefore [illegible] gm. / [illegible] cc. = 13.5[illegible]. The true volume of 6.000 cc. with mercury for this reading weighing 81.[illegible] gm. is obtained by dividing by 13.5[illegible] and equal to 6.[illegible]. That is, the buret at 6.[illegible] cc. - 6.00[illegible] cc. = + 0.001 cc. When the corrections for the various readings are determined as above they are plotted on graph paper and the plus or minus corrections for each 0.1 cc. reading of the buret are read off from the curve and listed for use.

As noted before, the calibration tap should be fused to the buret and not attached by rubber tubing, because changes in level of the mercury from the top to bottom of the buret will produce variations in pressure against the rubber [illegible] and consequently the latter will not always have the same bore, and an appreciable error in the calibration results.

[illegible]

[illegible]	[illegible]	Volume Hg in [illegible]	
[illegible]	Wt. of container plus Hg 9[illegible]	Wt. Hg in [illegible]	[illegible] =6.00[illegible] +.001
	Wt. of container	[illegible] Density Hg	13.[illegible]
		[illegible]	

Solutions for Haldane gas analysis: Potassium pyrogallate solution (Haldane): to [illegible] gm. of stick potassium hydroxide (not purified by alcohol as vapor will always be present and cause errors) are added [illegible] cc. of distilled water. The specific gravity of the resulting solution should be exactly 1.55 (this can be determined by [illegible] a hydrometer or by finding the weight of 100 cc. of the solution, which should be 155 gm.). If the specific gravity is too low, potassium hydroxide should be added until the desired concentration is obtained. To 100 cc. of this concentrated [illegible] solution 10 gm. of Merck's pyrogallic acid are added in a bottle with a [illegible] glass stopper. Haldane emphasizes that the solution must be made exactly [illegible] manner described otherwise unsatisfactory results are obtained. The resulting [illegible] of potassium pyrogallate should have a brownish-green tint and should become [illegible] this color immediately on exposure to air. The pyro should be at least [illegible] old before using, although it improves with age. This aging can sometimes [illegible] hastened by exposing the pyro for a few minutes to air and then giving it a [illegible]

Potash solution for CO_2 absorption: For the absorption of carbon dioxide we use a dilute solution of potassium hydroxide of specific gravity of about 1.09 - [illegible] containing [illegible] per cent solution.

[illegible] analyses or 25 high oxygen concentration analyses [illegible] solutions in the Haldane apparatus should be changed.

Technique of Haldane Gas Analysis (standard):

Setting levels: Pass sample already in apparatus back and forth several times alternately in both KOH tube and pyro tube to get rid of all CO_2 and O_2 in apparatus. Turn control tap 5 in position and always keep pyro tap 4 set for pyro tube during analysis. Set pyro level by turning KOH tap 3 to pyro tube. Level exactly by raising or lowering the mercury bulb. Turn KOH tap 3 to potash tube and set potash levels of buret X and of control tube Y exactly by raising or lowering the mercury bulb for the KOH level and raising or lowering the KOH reservoir to set the control level. Close the control tap 5. Whenever readings are to be made on the buret the pyro and the two potash levels must be very accurately set at the proper levels for X and Y. Before starting the analysis the control tube tap 5 must be closed and must never be opened during analysis.

If available a small steady stream of air must be constantly bubbled through the water bath. Otherwise a hand bulb like those used on blood pressure apparatus may be used and should be pressed before each reading. The water must be as high as possible in the water bath. Once the control tap is closed to room air it cannot be opened again until the completion of the analysis. At the end of the analysis the control tap should be opened in order to reset all the levels at the existing atmospheric pressure and to compensate for marked temperature changes. In this case it is not necessary to recheck the machine. Sometimes a T type of tap is used for the buret and is all right if the buret is properly calibrated. Such a tap, however, cannot be used for high concentrations of oxygen.

Transference of the sample to the buret: Turn sampling tap 1 and turn buret tap 2 to open the buret to room air only. Rinse the buret with room air by raising or lowering the mercury reservoir between 2 and 6 cms. four times. Hang the mercury reservoir on the ratchet so the mercury is half way in the bulb. The sample set is connected to the buret by means of a small sampling tubing and the sampling set tap opened to the buret. The index finger of the left hand is moistened with water and placed very tightly on top of the buret. The mercury reservoir is held in the right hand which is brought to a comfortable position on the top of the Haldane board. The air in the buret is then allowed to escape very gradually beneath the moistened index finger until the mercury has risen up to tap 2 - not in it. Tap 1 is turned and the sample will run into the buret and the mercury should fall to about 2 or 3 cm. on the buret. With the moistened index finger held very tightly on the top of the buret, tap 1 is turned and the air allowed to escape until the mercury rises up to tap 2. At the end of the fifth rinsing the mercury reservoir is lowered until the mercury is about 9.5 cms. in the buret. Tap 1 is now to be left . Hang the mercury reservoir on the ratchet. Equalize the pressure in the sample set by leveling the mercury in the sample set tube. When these two levels are set bring the mercury in the buret down below 9.5 cm. Check levels. Close the sample set tap, then open buret tap 2 to solutions . Pinch KOH tubing and the tubing connected to the mercury reservoir gently. Set KOH level X and Y very accurately. Take the volume reading. Check this reading after pinching the tubing and resetting the levels X and Y.

Absorption of the CO_2 and O_2: To absorb the CO_2 shunt the sample of air back and forth in the KOH solution (by raising and lowering the mercury reservoir in the bulb between 2 and 5 cm. ten times). Hang mercury reservoir on ratchet. Set levels X and Y and read the buret. To get a check reading shunt the air 8 times more in the KOH solution. The reading must check within .001.

To absorb the oxygen turn tap 3 $\ominus$. Shunt the air back and forth into the pyro solution 15 times. Set approximate level in pyro tube. Turn tap 3 $\oplus$. Shunt the air in the KOH 3 times to pick up the air containg O_2 which is in the potash tube. Set approximate levels in potash tube. Turn tap 3 $\ominus$. Repeat this entire procedure two times, the second time set the pyro level accurately and turn tap 3 $\oplus$ then set potash level before the first oxygen reading is taken. Check the oxygen reading twice by shunting the air 15 times in the pyro. The reading must check within .001.

Sample Calculations

Buret Reading		Corr.		Corr. - Read		Diff.	% Calculation
9.377	+	.003	=	9.380			
9.136	+	.007	=	9.143	=	0.237	$\frac{0.237}{9.380}$ = 2.53 % CO_2
7.443	+	.020	=	7.464	=	1.679	$\frac{1.679}{9.380}$ = 17.90 % O_2

Care of the Apparatus: Taps must be well greased and for this purpose lanolin may be used. When the sampling tubes become dirty they may be cleaned with concentrated nitric acid, rinsed with distilled water, and thoroughly dried. However, etching sometimes develops which cannot be removed. An excellent glass cleaning solution can be made up by using 25 grams of $KaCr_2O_7$ (potassium bicromate), 150 cc. of water, and 100 cc. of H_2SO_4 (Sulphuric acid). Add sulphuric acid to water and potassium bicromate very very slowly. This solution causes no etching. Cleaning once every six to twelve months is usually sufficient. Under no conditions should either alcohol or ether be used in cleaning any part of the apparatus as vapors from these may remain and interfere with accuracy of results.

To Clean Haldane Apparatus

If pyro or potash has been "sucked" over into the buret it must be cleaned at once so that the buret will not become etched and thus change its volume. To clean it use the following procedure: Open tap 1 $\ominus$ and tap 2. Attach rubber tubing to top of buret and allow the free end of the tubing to lie in a beaker of distilled water. Lower mercury reservoir bulb; thus drawing water from the beaker into the buret. Do not let water get as far down as the mercury rubber tubing. Then by raising the mercury reservoir bulb, push the mercury up to the top of the buret, thus pushing out all excess water into the water beaker. After repeating this six or seven times, turn tap 2, and potash tap 3 $\ominus$ and pyro tap 4 $\ominus$. Attach rubber tubing with a glass funnel on open end of pyro tap, fill funnel with distilled water and let it run into buret to wash out connections, then turn tap 2 and repeat the first procedure until buret is clean. Test the mercury in the buret with litmus paper to be sure all acids or alkalies are out of buret. When a neutral reaction is obtained, the buret is clean.

To clean potash pipettes turn potash and pyro taps $\ominus$ and control tap $\ominus$. Take potash bulb from clamp and empty potash into sink. Clean potash bulb with dilute HCL, rinse thoroughly with distilled water and fill with new supply of potash. Clean pyro tube with distilled water by removing stopper from end of pyro tube and using rubber tubing with funnel. Remove all excess water from pyro tube before adding fresh pyro.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

HIGH OXYGEN ANALYSIS 6.1 CC. SAMPLE

The buret tap of a Haldane for use in analyzing high oxygen mixtures must always be of the three way double oblique type; a tap with a T type of bore must not be used. The bulb part of the buret should contain 6 cc. and the calibrated part of the buret 4.1 cc.; a total of 10.1 cc. For analyzing mixtures containing 40% or more oxygen check the residual nitrogen in the Haldane so that the amount in the buret for storage is between 6.0 and 6.1 cc. Gas mixtures below 40% oxygen can with this type of buret be analyzed directly without storing nitrogen provided a 10.05 cc. sample is used; of course samples containing less oxygen can be easily analyzed. If practically pure oxygen from a tank is to be analyzed then the sample taken in should be approximately 9.5 cc.

Transfer nitrogen into pyro tube by bringing mercury reservoir up so that the drop of water on top of the mercury is just in the bore of the buret tap which is then given a quarter turn to seal buret. Turn potash tap back to the potash tube. Open the buret tap to room air rinsing a few times then rinse five times with sample to be analyzed. Take about 7 cc. of sample in the buret, level bulb of sample tube carefully in the usual manner and close sampling tube tap. Close buret tap. Set the potash levels accurately and take sample volume reading (nitrogen is still stored in pyro tube). Shunt sample back and forth several times in the potash tube and take reading of carbon dioxide absorption until they check. Turn potash tap so that the buret is connected with the pyro tube and draw part of the nitrogen into the buret; pass sample back and forth into the pyro tube being careful at first not to push too much into the pyro tube until part of the oxygen in the sample is absorbed. After absorption is practically complete wash potash and pyro tube two or three times in the usual manner until check readings are obtained.

HIGH OXYGEN ANALYSIS 3.5 CC. SAMPLE

Check Haldane so that the reading is between 6.0 and 6.1 cc. Transfer nitrogen into pyro tube by bringing mercury reservoir up so that the drop of water on top of the mercury is just in the bore of the buret tap. Open the buret tap to room air rinsing a few times then rinse five times with sample to be analyzed. Take 3.5 cc. of sample in the buret bulb, level bulb of sample tube carefully in the usual manner. Close sampling tube tap. Close buret tap. Set pyro level by bringing mercury in bulb down slowly until the pyro is at the level mark; this must be done very carefully so none of the oxygen is absorbed during the process. When pyro level is set turn potash tap. Set potasl level. Take sample volume reading and then analyze sample in the usual manner. This method decreases the accuracy by about one half because of using a small sample. It also requires more practice to use correctly. It is a convenient and quick method and does not use up the pyro solution nearly as rapidly.

Example of Calculation:

	Reading		Buret Correct.		Corrected Reading		Diff.		Percent
N_2 Stored	6.068	+	.016	=	6.084				
Sample N_2	9.602	+	.002	=	9.604	=	3.520	=	Sample
CO_2	9.423	+	.004	=	9.427	=	.177	=	5.03 %
O_2	6.740	+	.016	=	6.756	=	2.671	=	75.88 %

CALCULATION OF HIGH OXYGEN ANALYSIS USING 7 CC. SAMPLE

Example - adding volume of stored nitrogen to both sample & CO_2 reading

	Reading		Buret Corr.		Corrected Reading		Nitrogen				Diff.		Sample		Percent
N_2 Stored	6.180	+	.001	=	6.181										
Sample	7.009	+	.002	=	7.011	+	6.181	=	13.192						
CO_2	6.692	+	.003	=	6.695	+	6.181	=	12.876	=	.316	÷	7.011	=	4.51 %
O_2	6.698	+	.003	=					6.701	=	6.175	÷	7.011	=	88.08 %

EXAMPLE - SHORT CUT WHEN NITROGEN DIFFERENCE IS TO BE SUBTRACTED

	Reading		Buret Corr.		Corrected Reading		Diff.		Sample		Percent
N_2 Stored	6.180	+	.001	=	6.181						
Sample	7.009	+	.002	=	7.011						
CO_2	6.692	+	.003	=	6.695	=	.316	÷	7.011	=	4.51 %
O_2	6.698	+	.003	=	6.701	=	N_2 6.181 − .006 = 6.175	÷	7.011	=	88.08 %

EXAMPLE - SHORT CUT WHEN NITROGEN DIFFERENCE IS TO BE ADDED

	Reading		Buret Corr.		Corrected Reading		Diff.		Sample		Percent
N_2 Stored	6.180	+	.001	=	6.181						
Sample	7.009	+	.002	=	7.011						
CO_2	6.692	+	.003	=	6.695	=	.316	÷	7.011	=	4.51 %
O_2	6.600	+	.003	=	6.603	=	N_2 6.181 +.092 = 6.273	÷	7.011	=	89.47 %

CALIBRATION OF GASOMETER

The gasometer readings are made on a steel tape usually fixed on the counterpoise tube. The tape is graduated to 0.10 cm. and is read by means of stationary markers to 0.05 cm. It is, therefore, necessary to determine the factor of the gasometer in order to convert the linear rise of the bell into a unit of volume. This factor is derived in the following manner; the bell of the gasometer is a cylinder, and the circumference of it is determined by measurement at several points from top to bottom, either with the bell in position or removed entirely from the gasometer. On one gasometer the following measurements of the circumference were taken with the bell in position:

Reading on tape cm.	Circumference of bell cm.
97	126.0
87	126.0
72	125.9
59	125.9
45	125.8
33	125.8
17	125.8
9	125.8
Average	125.9

Since the radius of a circle = $\frac{\text{circumference}}{2\pi}$, then the radius to the outside of the wall of the bell equals $\frac{125.9}{2 \times 3.1416}$ equals 20.038 cm. The radius to the inside of the bell is, therefore, equal to 20.038 cm. minus the thickness of the copper wall as determined by calipers. Thus the radius of the inside of the bell is:

$$20.038 \text{ cm.} - 0.046 \text{ cm.} = 19.992 \text{ cm.}$$

Since the area of a circle equals πr^2, then 3.1416×19.992^2 cm. = 1256 sq. cm. Therefore, the capacity of the bell corresponding to a rise of 1 cm. measured by the tape will be equal to 1 cm. x 1256 sq. cm. = 1256 cc. or 1.256 liters, the factor of the gasometer. We read the centimeter scale to the nearest half-millimeter corresponding to a change in volume of 63 cc.

DETERMINATION OF THE VOLUME OF A CLOSED CIRCUIT RESPIRATION APPARATUS

Explanation.- In using any closed circuit type of apparatus such as the Boothby-Collins type for experimental work, in which it is necessary to know the total volume of gas in the entire apparatus, the volume of the apparatus when the spirometer bell is set at a definite low position must be determined.

Equipment.- 1. Closed circuit type of respiratory apparatus.
2. Supply of pure oxygen (strictly 99.7% pure)
3. Haldane gas analysis apparatus.

Principle.- The entire apparatus is repeatedly flushed out with air so that it contains nothing but atmospheric air, the oxygen content of which is 20.93% if the apparatus has been efficiently washed out. This figure is checked by means of the Haldane gas analysis procedure. A known volume of oxygen is then introduced into the system and the gas again analyzed. The amount of oxygen in the resulting mixture can then be determined and the original volume of air can be calculated.

Method.- Air is flushed in and out of the closed circuit apparatus repeatedly by manually elevating and depressing the spirometer bell. If the apparatus is equipped with a motor driven blower, it is kept operating to aid in the circulation of the air. If the machine has no intrinsic means for circulating the air, a hand pump must be installed in the circuit which is operated during the flushing and the mixing operations to be mentioned below. (If a hand pump is used, care must be taken to determine the added volume of the hand pump and consider it in the calculations.) When adequate flushing has been completed (5-10 minutes) the rubber tubes normally leading to the mask are attached to two ends of a "T" tube. The remaining orifice of the T tube is closed with a rubber stopper containing an outlet tube (for sampling) which is in turn closed off with a pinch clamp, Thus the apparatus becomes a closed system containing nothing but atmospheric air. To thoroughly circulate the contents it is necessary to again operate either the motor driven blower or the hand pump for a period of 5 to 10 minutes. Four samples are withdrawn from the apparatus and analyzed to confirm the oxygen content of the air within the apparatus, and the temperature is recorded.

The pinch clamp on the sampling tube is released and air allowed to flow out until the spirometer is nearly empty at a point that can be reproduced at a later date if necessary. This point is established by allowing the revolving drum to make a complete revolution with the writing pen in contact with the paper.

Pure oxygen (99.7%) from a tank is run into the spirometer until the added oxygen will, if possible, be nearly equal to the air in the apparatus in order to obtain a value of around 50% in the final oxygen analysis. If one is inexperienced in analysis of high oxygen values in the Haldane apparatus, it is best to regulate the volume of oxygen added so that the final analysis is within the range of the direct analysis on the Haldane, The value of oxygen added is recorded on the revolving drum and later measured. The gases within the apparatus are thoroughly mixed by means of the motor driven blower or the hand pump, as the case may be. The level of the pen on the revolving drum is allowed to reach an equilibrium with the oxygen supply completely turned off. Temperature changes should be kept as low as possible because the system acts as a delicate gas thermometer so that slight changes in the temperature of the enclosed gas results in considerable changes in the level of the spirometer bell. Four samples of gas are then removed from the apparatus and analyzed for oxygen content.

Calculations.- A formula is derived as follows: (per cent of O_2 in atmospheric air x volume of air in the apparatus) plus (volume of O_2 added) - equals - (per cent of O_2 in the final mixture) x (volume of air in apparatus plus the volume of O_2 added). Thus: $(O_2\%_a \times V_a) + V_{o2} = O_2\%M\,(V_a + V_{o2})$

Where $O_2\%_a$ - Per cent of O_2 in the original air in the apparatus

V_a - Volume of air in apparatus measured at existing barometric reading and saturated with water vapor at temperature of spirometer.

V_{o2} - Volume of O_2 added at existing barometer reading and saturated with water vapor at the temperature of the spirometer (for most purposes the O_2 is considered 100% pure and not 99.7% pure).

$O_2\%M$ - Per cent of O_2 in the final mixture of air and O_2

This formula is solved for V_a as follows: $V_a = \dfrac{V_{o2}\,(1 - O_2\%m)}{O_2\%m - O_2\%a}$

Example: Where $O_2\%_a = .2093$, $V_{O2} = 12.11$ liters, and $O_2\%m = .4687$

$$V_a = \frac{(1 - 0.4687)\ 12.11}{0.4687 - 0.2093} = \frac{0.5313 \times 12.11}{.2594} = \frac{6.434}{.2595} = 24.80 \text{ liters}$$

This volume now stands for the existing barometer and temperature readings, saturated with moisture at the temperature of the spirometer.

[illegible]

The [illegible] on the sampling tube is [illegible] and [illegible] allowed to flow [illegible]. [illegible] to make a complete revolution with the rotating drum [illegible].

Free oxygen (O_2) from a tank in the room [illegible]. [illegible]

Calculations.— A formula is derived [illegible]

[illegible]

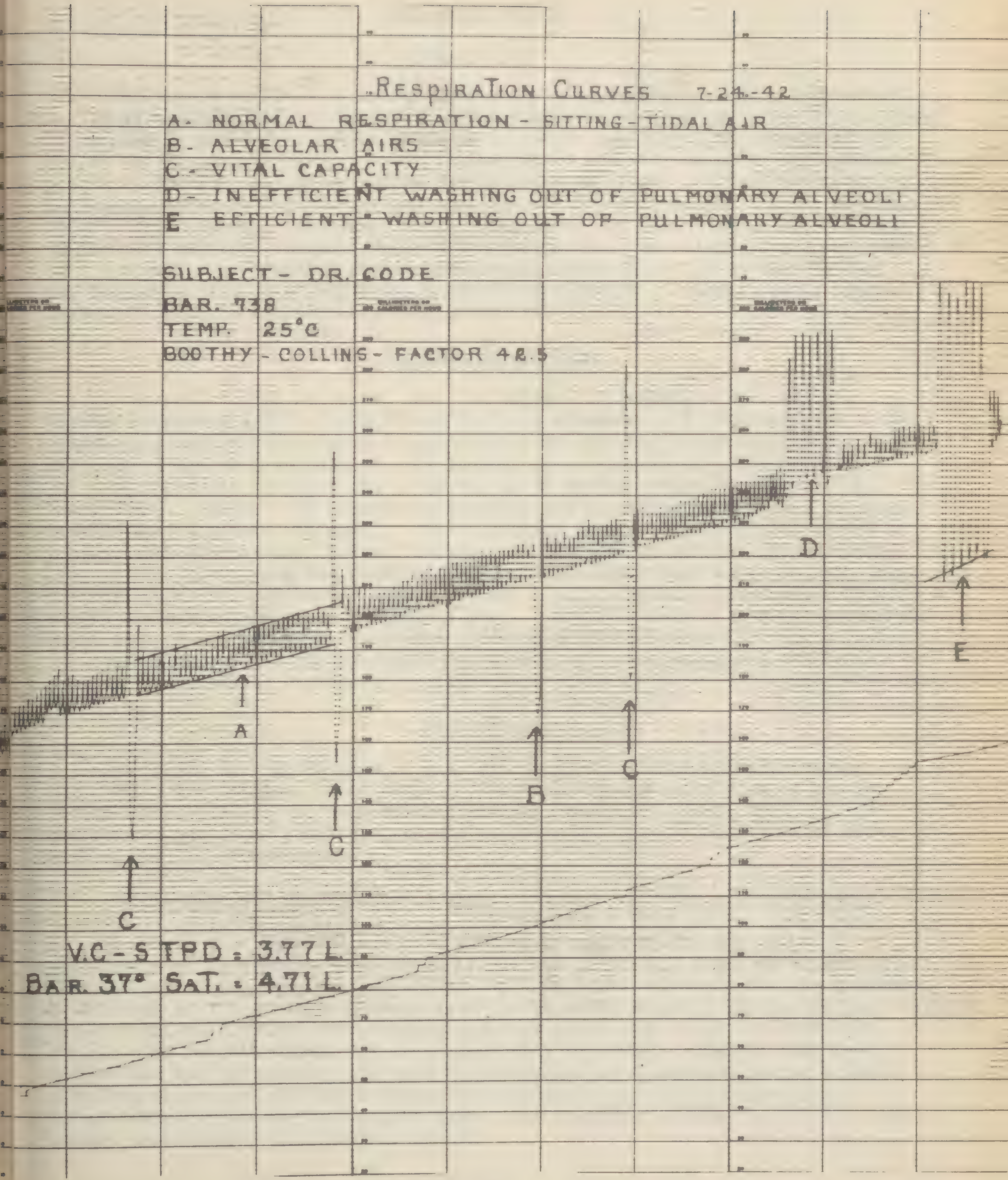
[illegible]

B. C. CLOSED CIRCUIT APPARATUS

WITH SUBJECT IN BODY PLETHYSMOGRAPH

B. C. CLOSED CIRCUIT APPARATUS ARRANGED

TO BE USED WITH BODY PLETHYSMOGRAPH


RESPIRATION CURVES 7-24-42
A- NORMAL RESPIRATION - SITTING - TIDAL AIR
B- ALVEOLAR AIRS
C - VITAL CAPACITY
D- INEFFICIENT WASHING OUT OF PULMONARY ALVEOLI
E EFFICIENT WASHING OUT OF PULMONARY ALVEOLI
SUBJECT - DR. CODE
BAR. 738
TEMP. 25°C
BOOTHY - COLLINS - FACTOR 42.5
A
B
C
C
C
D
E
V.C - STPD = 3.77 L.
BAR. 37° SAT. = 4.71 L.

PHYSICS OF GASES

Boyle's Law

Atmospheric pressure is measured by means of a barometer. This pressure at sea level and 45° latitude is normal and supports a column of mercury 760 mm. high If mercury is added to a J tube while it is on the same level in the closed arm and in the longer open arm, the air in the closed arm will be under atmospheric pressure, say 760 mm. After adding more mercury until its level in the open arm is 760 mm. above that in the closed arm, the air enclosed in the shorter arm is under two atmospheres pressure. At the same ti me the volume of air is reduced to half its original volume. Boyle's law states that the volume of a given mass of a gas kept at a constant temperature varies inversely as the pressure; that is, the concentration of a given quantitity of a gas at a constant temperature, is proportional to the corresponding pressure.

Absolute Temperature

In general it may be stated that the volume of a sample of gas at zero degrees increases 1/273 of its volume for each increase of 1 degree on the centigrade scale and decreases in the same proportion when the temperature falls. If the temperature were to fall to -273 degrees and the rate of contraction of a gas were to remain the same, then the volume of the gas would be zero at this temperature. Before -273 degrees is reached, all gases become liquids, to which the Charles' law does not apply. The centigrade degree is arbitrarily chosen as 1/100 of the temperature interval between the temperature of melting ice under a pressure of 760 mm. and the temperature of aqueous vapor from water boiling under the same pressure. The zero point therefore on a centigrade thermometer corresponds to 273 degrees on the gas, or absolute scale. Hence, absolute zero is 273 degrees below zero centigrade. In making the correction of the volume of a gas we convert the temperature to the absolute scale by adding 273 degrees to the centigrade reading; for example, 20 degrees centigrade is 273 plus 20 or 293 degrees absolute.

Charles' Law

The volume of a given mass of gas kept under a constant pressure varies directly as the absolute temperature. This statement is known also as the law of Gay-Lussac. It may be expressed otherwise; namely, the concentration of a quantity of gas under constant pressure is inversely proportional to the corresponding absolute temperature.

Correction of the Volume of a Gas to Standard Pressure and Temperature

If 100 ml of a gas were measured under a pressure of 740 mm. and at a temperature of 27 degrees, what would be the volume of this quantity of gas at standard conditions (760 mm. and 0 degrees)? Will the volume of the gas increase or decrease as the pressure changes from the original value of 740 mm. to the new value of 760 mm.? Since the pressure upon the given mass of gas is increased, the gas must be compressed. It is evident that to obtain a smaller number of millimeters for the volume, 100 must be multiplied by a fraction having a value less than unity. We therefore change the volume in an inverse proportion to the pressures by making the smaller number the numerator and the larger the denominator, and multiply the fraction by 100:

$$100 \text{ m.} \times \frac{740}{760} = 97.37 \text{ ml.}$$

[illegible]

Boyle's Law

Atmospheric pressure is measured by means of a barometer. This pressure at sea level and 0° [illegible] is normal and supports a column of mercury 760 mm. [illegible] If mercury is poured in a U tube while it is on the same level in the closed arm and in the open arm, the air in the closed arm will be under atmospheric pressure, say 760 mm. If then pouring more mercury until its level in the open arm is 760 mm. above that in the closed arm, the air enclosed in the shorter arm is under two atmospheres pressure. At the same time the volume of air is reduced to half the original volume. Boyle's law states that the volume of a given mass of a gas kept at a constant temperature varies inversely as the pressure; or, the concentration of a given quantity of a gas at a constant temperature, is proportional to the corresponding pressure.

Absolute Temperature

In general it may be stated that the volume of a sample of gas at zero degrees increases 1/273 of its volume for each increase of 1 degree on the centigrade scale and decreases at the same proportion when the temperature falls. If the temperature were to fall to -273 degrees and the rate of contraction of a gas were to remain the same, then the volume of the gas would be zero at this temperature. Before -273 degrees is reached, all gases become liquids, to which [illegible] law does not apply. The centigrade degree is arbitrarily chosen as 1/100 of the temperature interval between the temperature of melting ice under a pressure of 760 mm. and the temperature of aqueous vapor from water boiling under the same pressure. [illegible] -273 degrees on the centigrade scale [illegible] absolute scale. Hence, absolute zero [illegible] 273 degrees below zero centigrade. In making the corrections of the volume of a gas we convert the temperature to the absolute scale by adding 273 degrees to the centigrade reading; for example, 20 degrees centigrade is 273 plus 20 or 293 degrees absolute.

Charles' Law

The volume of a given mass of gas kept under a constant pressure varies directly as the absolute temperature. This statement is known also as the law of Gay-Lussac. It may be expressed otherwise; namely, the concentration of a quantity of gas under constant pressure is inversely proportional to the corresponding absolute temperature.

Correction of the Volume of a Gas to Standard Pressure and Temperature

If 100 ml. of a gas were measured under a pressure of 750 mm. and at a temperature of 20 degrees, what would be the volume of this quantity of gas at standard conditions (760 mm. and 0 degrees)? Will the volume of the gas increase or decrease as the pressure changes from the original value of 750 mm. to the new value of 760 mm.? Since the pressure upon the given mass of gas is increased, the gas must be compressed. It is necessary then to secure a smaller number of [illegible] for the answer, 100 must be multiplied by a fraction having a value less than unity. We therefore reduce the volume in an inverse proportion to the [illegible] by making the smaller number the numerator and the larger the denominator, and placing the fraction as follows:

$$100 \times \frac{750}{760} = 98.7 \text{ ml.}$$

The volume of the gas was measured at 27 degrees centigrade or 27 degrees plus 273 degrees equals 300 degrees absolute. Again the question arises as to whether the volume of the gas will decrease or increase the when temperature changes from 300 degrees absolute to 273 degrees absolute. The volume decreases, for according to Charles' law the volume varies directly as the absolute temperature. Consequently:

$$97.39 \times \frac{273}{300} = 88.61$$

and by combining the two equations, we have

$$100 \times \frac{740}{760} \times \frac{273}{300} = 88.61$$

It is customary to make the volume correction for both temperature and pressure in one operation. By orderly reasoning it will be easy to determine whether a change in temperature or pressure causes an increase or a decrease in the volume of a gas. Then the correction can be easily calculated after setting up the proper ratios.

Dalton's Law or Partial Pressure

In any mixture of gases each gas exerts the same pressure as if it were present alone in the volume occupied by all the components, and the total pressure of the mixture is equal to the sum of the partial pressure of the gases. The partial pressure of any gas is proportional to its concentration.

When a gas is measured over water, it soon becomes saturated with water vapor. The pressures of saturated water vapor for different temperatures may be looked up in tables. From Dalton's law it is evident that if the measurement is made at atmospheric pressure, the sum of the gas pressure and the water vapor pressure is equal to the barometric pressure. Hence, when a gas is measured over water at a given temperature, its pressure is obtained by subtracting the pressure of saturated water vapor at that temperature from the barometer reading. Suppose for example, that 100 ml. of oxygen is measured over water at a temperature of 27 degrees and a pressure of 740 mm. To obtain the correct volume of the gas under standard conditions we first look up the aqueous vapor pressure at 27 degrees. It is 26.75 mm. (27mm.). Hence, 740 - 27 = 713 mm. which is the pressure of oxygen alone. The product given by $100 \times \frac{713}{760} \times \frac{273}{300}$ represents the final volume in millimeters of the dry gas corrected to standard conditions.

Problems Involving Gas Laws

In aviation medicine it is frequently important to determine the volumetric changes that oxygen and other gases undergo during the flight of aircraft. These volumetric changes are easily computed if we correctly apply the Charles and Boyle laws to the problem to be solved.

The volume of the gas was measured at 27 degrees centigrade or 27 degrees plus 273 degrees absolute (300 degrees absolute). Since the original volume has to be reduced, the volume of the gas will decrease as the temperature changes from 300 degrees absolute to 273 degrees absolute. The volume decreases, in accordance with Charles' law, the volume varies directly as the absolute temperature. Consequently:

$$100 \times \frac{273}{300} = 91.0$$

and by correcting for the pressure, we have

$$100 \times \frac{740}{760} \times \frac{273}{300} = 88.61$$

It is necessary to make the volume correction for both temperature and pressure in one operation. By carefully reasoning out in which way a change of temperature or pressure causes an increase or a decrease in the volume of a gas, then the correction can be easily calculated after setting up the proper ratios.

Dalton's Law of Partial Pressures

In a mixture of gases each gas exerts the same pressure as if it alone were present, since it acts independently of the others. The total pressure of the mixture is equal to the sum of the partial pressures of the gases. The partial pressure of any gas is proportional to its concentration.

When a gas is measured over water, it must be saturated with water vapor. The pressure of water vapor present at different temperatures may be found in tables. From Dalton's law it is evident that if the measurement is made at atmospheric pressure, the sum of the gas pressure and the water vapor pressure is equal to the atmospheric pressure. Hence, when a gas is measured over water at a given temperature, its pressure is obtained by subtracting the pressure of saturated water vapor at that temperature from the barometric pressure. Suppose, for example, that 100 ml. of oxygen is measured over water at a temperature of 27 degrees and a pressure of 750 mm. To obtain the correct volume of the dry gas under standard conditions we first look up the aqueous vapor pressure at 27 degrees. It is 26.7 mm. (about 27 mm.). Hence, 750 - 27 = 723 mm. which is the pressure of the oxygen alone. The product given by $100 \times \frac{723}{760} \times \frac{273}{300}$ represents the final volume in milliliters of the dry gas corrected to standard conditions.

Problems Involving Gas Laws

In analytical chemistry it is frequently important to determine the volumetric changes that hydrogen and other gases undergo during the course of a reaction. These volumetric changes are readily computed if we correctly apply the Charles and Boyle laws to the problem to be solved.

Sample Problems

1. What is the volumetric change in a gas when one liter of oxygen in a tank reaches the lungs at 10,000 feet?

In answering this problem we must remember that oxygen in a tank is measured as it flows out by a meter calibrated to give readings at S.T.P.D. (standard temperature, pressure, dry = 0 degrees C., 760 mm. Hg, dry) and that water vapor correction must be made only for the oxygen in the lungs, which is 47 mm. Hg because the lung temperature is 37° C. Therefore, our formula begins as

$$\frac{760 \text{ (standard pressure)}}{523 (10{,}000 \text{ ft. Bar. Press.}) - 47 \text{ (water vapor pressure at } 37^\circ\text{C.)}} \text{ or } \frac{760}{523 - 47} \times 1 \text{ (liter)}$$

By applying Boyle's law we know that 760 is the numerator since lowered pressures increase the volume of gases (temperature remaining constant) and to obtain a larger number of liters of oxygen, 1 liter must be multiplied by a fraction having a value more than unity. We must also here consider temperature changes. Since the oxygen in the tank is measured as though it were at 0° C (273 absolute) and the lung temperature is 37° C (273 plus 37 absolute) and since by applying Charles' law we know that the increase in temperature from tank to lungs will increase the volume of the gas, then our temperature correction becomes

$\frac{273 + 37}{273} \times 1$ and by combining the two, we have

$$1 \times \frac{760}{523 - 47} \times \frac{273 + 37}{273} = 1 \times 1.597 \times 1.135 = 1.813 \text{ liters of } O_2 \text{ in the lungs.}$$

2. One liter of gas in the human stomach at sea level changes to what volume during an ascent to 10,000 feet (523 mm. Hg)?

The volume must increase as the pressure dec ases. Moreover, the gas is maintained under body conditions, so the water vapor correction must now be made in both the numerator and denominator of our formula. Thus we have $\frac{760 - 47}{523 - 47} \times 1$. This is the completed formula because no temperature correction is needed, as the body temperature remains constant. Therefore,

$$\frac{760 - 47}{523 - 47} \times 1 = \frac{713}{476} \times 1 = 1.50 \text{ liters}$$

3. One liter of oxygen in a dry toy balloon is taken from sea level to 10,000 feet in a low pressure chamber. What is the volume of the balloon at 10,000 feet altitude? This is relatively simple in that no water vapor or temperature correction is required.

Hence $\frac{760}{523} \times 1 = 1.45$ liters

Of course, if the toy balloon were taken to 10,000 feet outside of a low pressure chamber (i.e. pilot balloon or sounding balloon) then corrections would have to be made for temperature also.

THE PRESSURE CHAMBER

Before starting: Keep an accurate log of all chamber runs showing:

A. Mission to be carried out.
B. Names of all subjects and respective duties on mission.
C. Time of reaching each 5,000 foot elevation.
D. Note any symptoms of anoxia or aero-emphysema reported by subject and make inquiries at appropriate altitudes.
E. Note time of starting and ending any experimental procedure and the elevation at which it is done.
F. Note time and the number of the sample set and of the tube when used.
G. Be sure observer is properly recording any data he is taking inside chamber. Crucial points should be correlated in time by outside observer. It will usually be impracticable to report over loud speaker but times should be recorded so that after descent to ground level the inside and outside data can be correlated immediately.

Technic for running Pressure Chamber:

1. For chamber equipped for both positive (diving) and negative flying pressure be sure valves are properly turned for mission.
2. Turn on motor.
3. Set manometer for existing barometer.
4. Turn on loud speaker.
5. Be sure the oxygen tanks of manifold contain sufficient pressure.
6. Test oxygen regulator inside chamber to see that oxygen will flow properly.
7. Fit mask to subjects and be sure all subjects understand equipment and duties.
8. Before closing door check for emergency mask, paper, pencils, stop clock, time piece, pliers, wrenches and any other apparatus needed for this particular flight.
9. Close door.
10. Close large valve in front of big door.
11. Check oxygen flow with subjects inside chamber and at each level check flow again.
12. When going up the door in front may have to be tightened because of the negative pressure. Also on coming down the doors should be gradually loosened so they will open readily when at ground level.
13. When you reach the ground open the door, (after first opening safety valve on door), turn off motor, oxygen flow and loud speaker.
14. No one should go up in the chamber alone. It is better to have two persons in the chamber to check each other. When coming down from whatever altitude they have reached, the rate of descent depends on the subjects' symptoms regarding the ears and sinuses.

INDIVIDUAL LOW PRESSURE CHAMBER

GENERAL SET UP FOR TREADMILL EXPERIMENTS

N_2 ELIMINATION

AT REST

AT WORK

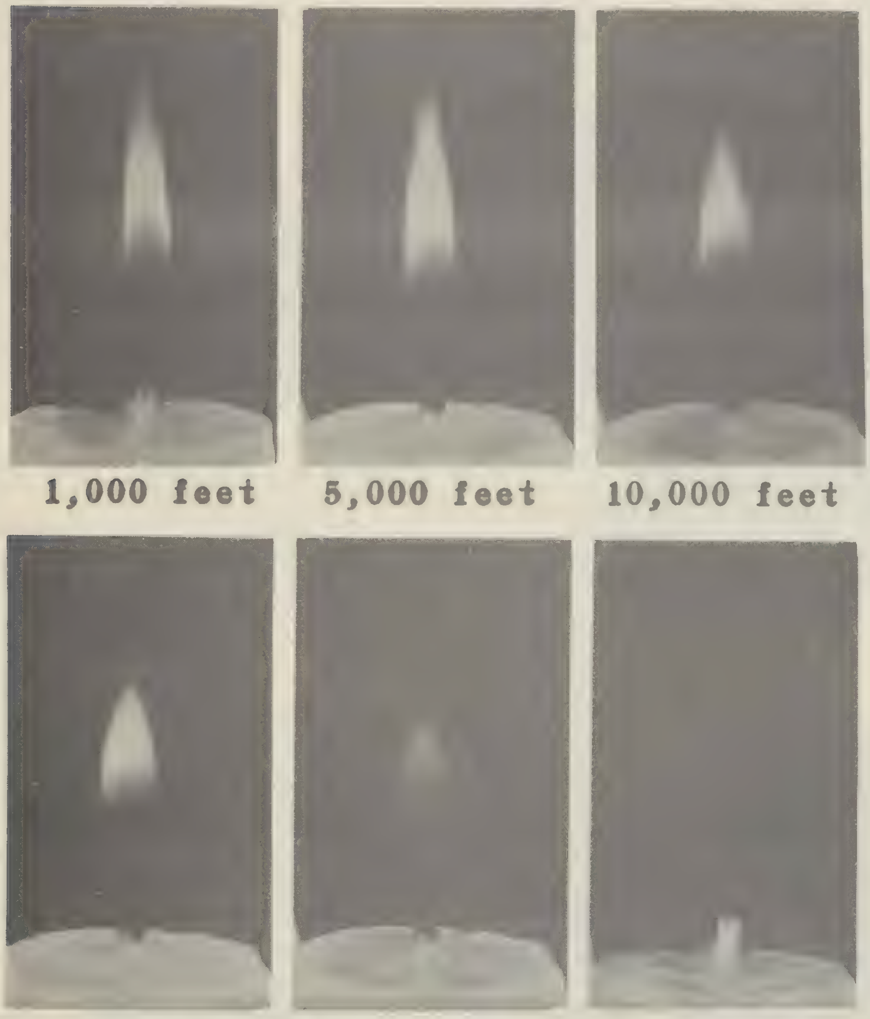
APPARATUS TO FILL SMALL OXYGEN TANK

FROM

LARGE COMMERCIAL CYLINDER

ONE FORM OF EMERGENCY BAIL OUT APPARATUS

EFFECT ON CANDLE FLAME
OF DECREASE IN BAROMETRIC PRESSURE



1,000 feet 5,000 feet 10,000 feet

15,000 feet 20,000 feet 25,000 feet (Still burning)

Slide 1-16. Dr. Boothby (gg

A TYPE OF SAFETY BELT TO PREVENT HEAD INJURY
DESIGNED BY
F.E. MCDONOUGH, M.D., and M.N. WALSH, M. D.

MAYO AERO MEDICAL UNIT
ROCHESTER MINN.

EXAMPLE OF A CHAMBER RUN

In chamber: Subject - Dr. M. R. Halbouty - Without oxygen.
Observer - Lucille Cronin - B.L.B. Nasal Mask

Date: December 22, 1941
Barometer: 731

	10:22	Door and valve closed.
	10:25	5,000 feet
	10:27	10,000 feet
	10:30	15,000 feet
	10:31	18,000 feet
	10:31:20	Peg test - Dr. Halbouty
	10:33	Code test - Dr. Halbouty
	10:35	Code test - Dr. Halbouty
	10:45	Peg test - Dr. Halbouty
S.S. *55	10:47	Alveolar sample taken - Dr. Halbouty - 9.85%-33 mm. Hg CO_2 10.41%-35 mm. Hg O_2
	10:56	Code test - Dr. Halbouty
	10:58	Code test - Dr. Halbouty
	11:02	Peg test - Dr. Halbouty
S.S. *55	11:04	Alveolar sample taken - Dr. Halbouty - 9.30%-31 mm. Hg CO_2 10.73%-36 mm. Hg O_2
	11:04:10	Started down
	11:04:30	15,000 feet
	11:05:15	10,000 feet
	11:06:30	5,000 feet
	11:09	Ground

* Sample set

GAS BUBBLE FORMATION AT HIGH ALTITUDES

In order that one may better understand the formation of gas bubbles in the body at high altitudes, a simple experiment has been devised to demonstrate it. Instructors in aviation medicine will find the demonstration to be of value for teaching purposes, especially as regards aeroembolism and aeroemphysema, which are found when rapid ascents are made to high altitudes without proper preliminary decompression or denitrogenization.

The apparatus needed includes the following: a mercury manometer, rubber and glass tubing, a gallon bottle with a one-hole perforated stopper and a suction apparatus capable of creating a negative pressure (the low pressure chamber may be used for this purpose: or if necessary an ordinary hand suction pump may be used); should a mercury manometer not be available an altimeter may be placed in a small bell jar low pressure chamber to indicate altitudes simulated. Of course the bell jar chamber is to be connected to the rest of the apparatus in place of the manometer.

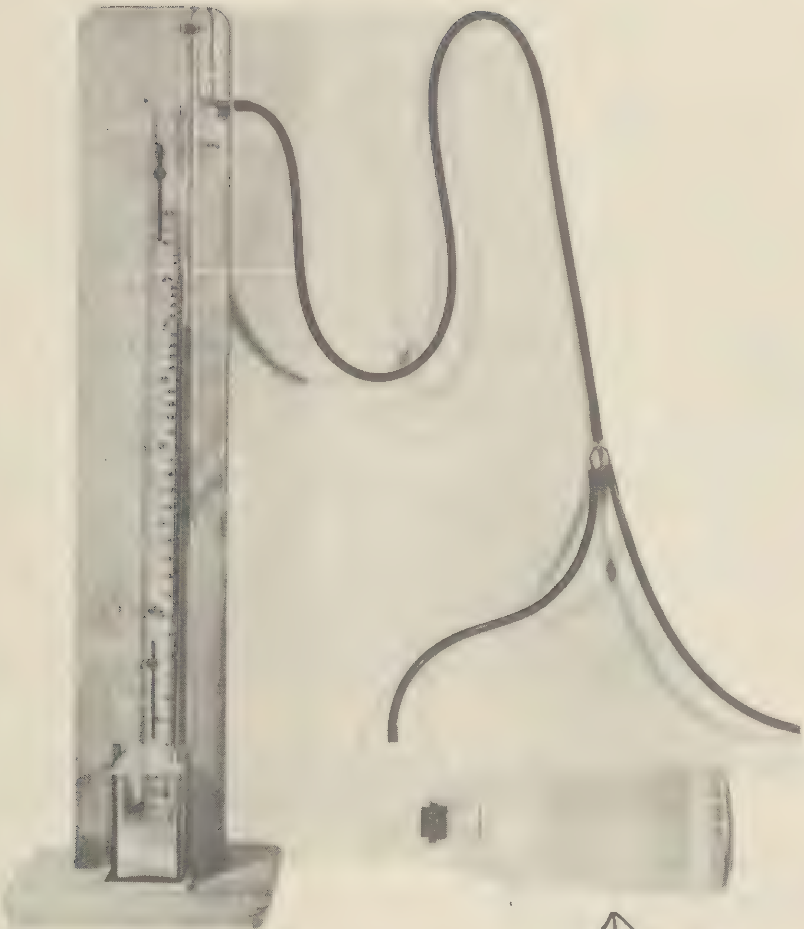
The apparatus is connected as shown in the labeled diagram. The gallon jar should be filled with tepid water.

Turning on the suction apparatus causes the mercury in the manometer to rise due to the negative pressure. Controlling the amount of negative pressure also controls the level of the mercury column so that any reasonable altitude can be simulated - depending on the amount of negative pressure produced. Of course,

if the negative pressure source is the low pressure chamber, then altitudes may be simulated in the water-bottle manometer corresponding to those reached by the low pressure chamber. In fact the bottle or even an open beaker of water can be taken up in the chamber with each class of students.

The bubbles often begin forming at altitudes of 12-15,000 feet. At first these bubbles are microscopic in size, but wi th the reaching of higher altitudes larger bubbles are formed by fusion and by expansion of the smaller bubbles; a variation in the refraction of light through the water will be noted if sudden changes in pressure are produced. This may be better illustrated if a light source is placed behind the bottle.

AERO-EMPHYSEMA
BUBBLE FORMATION



TO VACUUM

MERCURY
ALTIMETER

BOTTLE CONTAINING WATER WITH
TUBE INTRODUCED FROM SIDE TO
REPRESENT NEEDLE IN SPINAL
CANAL

THE PRINCIPLES AND CONSTRUCTION OF FLOWMETERS

Principle: There are two main types of flowmeters: (1) Kinetic or float type of flowmeter and (2) Static or pressure type.

The first, the float type depends upon the pressure of a flowing column of gas elevating a ball or plunger in a tube with gradually increasing bore. In this type the pressure of the flowing gas overcomes the gravitational force of the ball or plunger. The tube must be maintained at a standard inclined position so that the weight of the indicator supported by the pressure of the gas is always comparable. The tube is so constructed that the internal diameter at its base is slightly larger than the base of the plunger or the diameter of the ball indicator. The bore of the tube is such that the internal diameter of the tube increases gradually from its base to the upper end, the increase in size or pitch of the walls of the tube may be uniform throughout or it may be divided into sections with different pitch in each section, so that as the flow becomes larger the scale can be contracted. When gas flows into the bottom of the tube, the base of the plunger (for example) is elevated in the venturi tube by the pressure of gas beneath it. The higher the plunger is elevated the greater is the space between the base of the plunger and the inside wall of the tube so that the gas can more easily flow past. When oxygen is being supplied by a reducing valve so that a steady flow of oxygen is being introduced into the venturi tube, the plunger will be elevated to a definite point where it will remain because an equilibrium is reached such that the space about the periphery of the plunger is just large enough to allow sufficient gas to flow on through the tube to maintain a pressure under the plunger exactly equal to the weight of the plunger. When the plunger has been elevated to a definite height by a definite flow of gas, this flow of gas can be calibrated on a scale parallel to the tube by comparing the oxygen delivery with a previously calibrated master flowmeter, preferably in a bell jar or low pressure chamber at each altitude. This master flowmeter must be previously calibrated by weight for the required mass of gas desired and must be done either in a large chamber or in a bell jar evacuated to the desired altitude pressure.

The great advantage of a kinetic type of flowmeter is that it does not indicate flow unless flow is occurring.

The second type of flowmeter is the static type and does not truly indicate flow but merely the pressure in a pipe back of a given sized orifice which if patent will give a known rate of flow, a pressure gauge can thus be readily calibrated to indicate flow. The usual type of pressure gauge is used which is based on the principle of a Bordin tube which is curved and tends to straighten out in proportion to increase in pressure of gas or fluid inside tube; by means of gears small movements of the tube can be transferred to an indicator needle and the rate of flow for a given pressure can be calibrated on a dial.

As in the kinetic type the static type must also be calibrated to give the desired flow at that altitude. The dangerous fact in regard to a static or pressure type of flowmeter like this just described is that it may indicate a "flow" where no flow is occurring even if it accurately records the pressure in the pipe back of the "port hole."

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

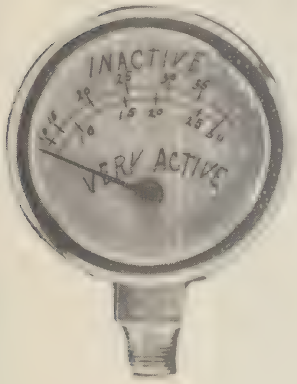
[illegible]

[illegible]

FLOW METERS

BOTH TYPES MUST BE CALIBRATED FOR DELIVERING
AT EACH ELEVATION

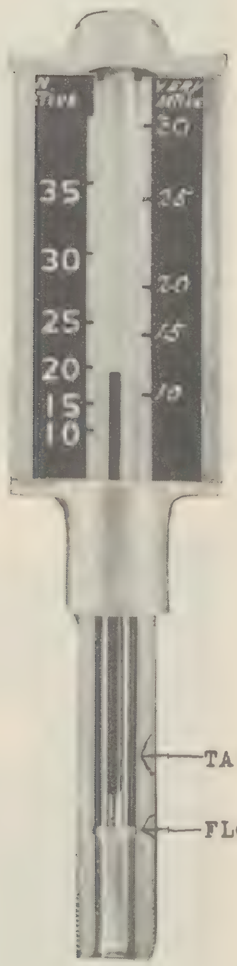
STATIC
OR
PRESSURE TYPE
FLOW METER



FRONT VIEW

BACK INSIDE VIEW
SHOWING CURVED METAL TUBE
OF THE BORDEN TYPE WHICH
TENDS TO STRAIGHTEN OUT
AS THE PRESSURE INSIDE TUBE INCREASES

KINETIC
OR
FLOAT TYPE
FLOW METER



TAPERED TUBE

FLOAT

TUBE CONTAINING FLOAT IS CONE
SHAPED SO THAT THE HIGHER IT IS
RAISED BY THE FLOW OF OXYGEN
THE GREATER THE AMOUNT OF FLOW
AROUND THE SIDE OF THE FLOAT

BELL JAR LOW PRESSURE CHAMBER FOR TESTING SMALL INSTRUMENTS AT HIGH ALTITUDE

OXYGEN DEMAND SYSTEM
APPARATUS FOR MEASURING AMOUNT OF OXYGEN
USED BY SUBJECT

THE SMALL TANK IS FILLED TO A GIVEN PRESSURE FROM BIG TANK. THE AMOUNT OF OXYGEN USED IS DETERMINED BY TAKING THE TIME NEEDED FOR THE PRESSURE TO DECREASE IN MULTIPLES OF 100 lbs.

BUBULIAN
DEMAND TYPE MASK WITH RESERVOIR REBREATHING BAG TO ALLOW USE OF CONSTANT FLOW AS WELL AS THE DEMAND PRINCIPLES.

QUANTITATIVE OXYGEN DETERMINATIONS

The quantitative determination of oxygen used may be desired at times. Need for this is found in determining active and inactive flows through various apparatus. Oxygen regulators can thus be checked for the flow the regulator allows at various altitudes and under various amounts of exercise. A wet test flowmeter can thus be checked as can oxygen consumption of individuals under various conditions.

There are various methods for these determinations. Several will be considered here. Probably the simplest of these is by using only a tank of oxygen, rubber tubing and an oxygen mask.

As an example, let's create a problem: We wish to determine the amount of oxygen used by an individual active for 3 minutes at an altitude of 15,000 feet. Our "active" individual does about 1200 foot-pounds of work per minute - 1260 foot pounds to be exact. We use a 12 pound weight and raise it 3.5 feet for 30 times in one minute (12 x 3.5 x 30 = 1260 foot pounds). It must be realized that this calculated amount of work is only theoretically present, however, biologically more than this amount of work is done because the theoretic calculation only considers lifting, wereas biologically the individual is also doing work when he lowers the weight since he is acting against the force of gravity here, too.

Equipment needed:

1. Two 100% oxygen tanks - preferably 100 gallon size.
   A. Tank #1 - To be weighed.
   B. Tank #2 - Not to be weighed.
2. Rubber tubing connections.
3. Oxygen mask.
4. Accurate balance - reading accurately to 10 mgm. with kgm, weight.
5. Low pressure chamber.
6. Stop watch.
7. 12 pound weight for weight-lifting exercise.
8. Metronome for timing exercise.
9. Reducing valve and an aviation flowmeter mounted on the base only of a bell jar chamber (the glass cover is not needed here). The set up is as drawn in the illustration on "Checking Aviation Flow Meter Using a Master Flow Meter" except that the glass jar and mercury manometer are not needed, and only one flowmeter is needed.

Procedure:

1. Weigh the oxygen tank #1 and record weight.
2. Connect the apparatus as described.
3. Place the apparatus in the chamber with the subject.
4. Ascend to 15,000 feet using the oxygen system and mask of the chamber.
5. Attach O_2 tank #2 to bell jar base, taking care to check the washer at this connection.
6. Turn on flow of O_2 tank # 2.
7. Set flowmeter at the altitude to be checked (15,000 feet active.)
8. Shut off tank # 2 and remove it.
9. Connect tank # 1 to bell jar base.
10. Remove the regular chamber mask from the subject, place the experimental mask on him, turn on the oxygen flow of the 100 gallon tank while being careful to start the stop watch simultaneously with the oxygen flow. As soon as the oxygen flow is started the subject begins his exercise by raising and lowering the 12 pound weight 3.5 feet for 30 times per minute.

11. At the end of 3 minutes shut off the small #1 tank's flow the instant flowmeter level drops, have the subject stop work, and reconnect him to the oxygen flow system of the chamber.
12. Descend to ground level.
13. Weigh tank #1 again and record.
14. Sample calculation:

Wt. of O_2 tank before test	= 6080.891 gms.	(See section on "Selection of a Master Aviation Flow Meter Using Determination of Flow Rate by Weighing" for weighing procedure.)
Wt. of O_2 tank after test	= 6073.891 gms.	
Tank Weight Loss	= 7.000 gms.	

$$\frac{\text{Mol. Wt. of } O_2}{22.4} = \frac{32}{22.4} = 1.429 \text{ gms.} = \text{Wt. of one liter of dry } O_2.$$

$$\text{Therefore } \frac{7.000}{1.429} = 4.899 \text{ liters } O_2 \text{ used in 3 minutes}$$

$$\text{and } \frac{4.899 \text{ liters}}{3 \text{ min.}} = 1.633 \text{ liters } O_2 \text{ used in 1 minute.}$$

We must realize that this method even though relatively simple has its limitations. It is dangerous to use this method at higher altitudes such as 35,000 to 40,000 feet, for at these altitudes one may lose consciousness in about 35 seconds or less. Such a situation may be met if there is any delay in changing over from the oxygen supply system of the chamber to that of the small tank or vice versa. It is probably best to reserve this method for determining quantitative oxygen flow to altitudes below 20,000 feet unless a two-way valve is used so that one may readily switch from one oxygen system to the other by merely turning a tap.

In connecting up an oxygen regulator to the above system and setting the regulator for a certain altitude and physical exercise (i.e. 15,000 feet active) we may also determine if the regulator is supplying the correct amount of oxygen for that altitude and resting or exercise state. (See section of "A Master Aviation Flow Meter Using Determination of Flow Rate by Weighing".)

We can attach a wet test flowmeter to the above apparatus, record the number of liters of O_2 the wet test flow meter dial shows as having flowed through for a given period of time and compare this recording with the flow calculated by weighing the oxygen tank as outlined above. Thus we can check the accuracy of the wet test flow meter.

This leads us to our second method of determining the quantitative flow of oxygen. Assuming our wet test meter is accurate, connect it to an oxygen tank with flowmeter so that all oxygen going to the mask has to first flow through the wet test meter. By merely noting the reading on the wet test meter dial at the beginning and end of each test we can learn the ambient amount of oxygen which has been used. However this reading must be corrected to S.T.P.D. to give us the reading commonly used. Assume that the test is conducted at 10,000 feet altitude with a barometric pressure of 523 mm. Hg and the temperature reading of the wet test meter is 25 degrees C. (temperature must be taken in this method). By looking at the tables of water vapor we note that the water vapor for 25 degrees C. is 23.8 (or 24.0). If 6 liters of oxygen flow is recorded in 10 minutes, then 6.0 liters = .60 liters/min. measured at ambient temperature and pressure flowed through the meter.

11. At the end of 3 minutes shut off the small O_2 tank [illegible] the [illegible] of the [illegible] level drops, bring the subject stop work, and reconnect him to the oxygen [illegible] [illegible] of the [illegible].

12. [illegible] to ground level.
13. [illegible] tank #1 again and record.
14. [illegible]

Wt. of O_2 tank before test	= [illegible] gms.		(The weight, or difference of a certain
Wt. of O_2 tank after test	= [illegible] gms.		[illegible] flow meter during the [illegible]
Tank weight loss	= [illegible] gms.		[illegible] flow meter by [illegible] [illegible] [illegible] [illegible])

$$\frac{[illegible]}{[illegible]} = \frac{[illegible]}{[illegible]} = 1.4[illegible] \text{ gms.} = \text{Wt. of one liter of dry } O_2.$$

Therefore $\frac{[illegible]}{[illegible]} = 4.9[illegible]$ liters O_2 used in 2 minutes

or $\frac{[illegible] \text{ liters}}{[illegible]} = 1.4[illegible]$ liters O_2 used in 1 minute.

We must realize that this method even though relatively simple has its limitations. It is dangerous to use this method at higher altitudes than [illegible] to [illegible] feet, for at these altitudes one may lose consciousness in about 35 seconds or less. Such a situation may be met if there is any delay in changing over from the oxygen supply system of the chamber to that of the small tank or vice versa. It is necessary then to compare this method for determining quantitative oxygen flow at altitudes below [illegible] feet where a [illegible] [illegible] is used so that one may readily switch from one system to the other by merely turning a tap.

In connecting up an oxygen regulator to the above system and setting the regulator for a certain altitude and physical exercise ([illegible]) [illegible] we may also determine if the regulator is supplying the correct amount of oxygen for that altitude and setting or exercise status. (See section of "A [illegible] Aviation Flow Meter Using a Calibration of Flow Rate by Weighing").

We can check a wet test flowmeter to the above apparatus, record the number of liters of O_2 the wet test flow meter dial shows as having flowed through for a given period of time and compare this measurement with the flow calculated by weighing the oxygen tank as outlined above. Thus we can check the accuracy of the wet test flow meter.

This leads up to our second method of determining the quantitative flow of oxygen. Attaching our wet test meter to [illegible], connect it to an oxygen [illegible] with flowmeter so that all oxygen going to the mask has to first pass through the wet test meter. By merely noting the reading on the wet test meter dial at the beginning and end of each test we can know the [illegible] amount of oxygen which has been used. However this reading must be corrected to S.T.P.D. to give us the reading commonly used. Assume that the test is conducted at 10,000 feet altitude with a barometric pressure of [illegible] mm Hg and the temperature reading of the wet test meter is 25 degrees C. (Temperature must be taken in this method). By looking at the tables of water vapor we note that the water vapor [illegible] of [illegible] C. is 23.8 (or 24.0). If 6 liters of oxygen flow is measured in 10 minutes, then 6.0 liters = .60 liters per minute at ambient temperature and pressure flowed through the meter.

Correcting to S.T.P.D. (760 mm. Hg 0° C., Dry) then

$$.60 \times \frac{523 - 24}{760} \times \frac{273}{273 + 25} = .60 \times .657 \times .916 = .36 \text{ liters } O_2\text{/min. at S.T.P.D.}$$

With this method there is no need to weigh the oxygen tank, and it is relatively safe in that there is no need to change oxygen masks as one merely continues to use the chamber oxygen system the whole time he is in the chamber. This method is commonly used to check the flow of regulators connected to this system.

There is still another method of determining the amount of oxygen used. We have used it mostly in testing regulators. It is excellent for testing regulators and masks used with either the demand system or constant flow system.

The equipment is shown in illustration QDO2.

Equipment needed:

1. Paper and pencil.
2. An oxygen tank - standard size is satisfactory.
3. A small accessory oxygen tank for measuring. (The volume for a drop of 100# pressure has been predetermined by methods previously mentioned.)
4. A pressure gauge for the accessory oxygen tank.
5. Low pressure chamber.
6. Oxygen mask and tubing.
7. Stop watch or electric stop clock preferably calibrated for tenths and hundredths of a minute.
8. Weight for lifting exercises (preferably 12#).
9. Oxygen regulator.
10. Metronome for timing exercise.

Assume that our problem is to determine amount of oxygen used per minute with a regulator and mask designed for a demand system at an altitude of 20,000 feet while actively exercising.

Procedure:

1. Draw an outline form on paper as follows:

Altitude	Starting pressure in tank	End pressure in Tank	Pounds used	Time in min.

2. Connect the apparatus in the chamber as noted in illustration QDO2. The valve on the large tank is slowly opened so that oxygen flows into the small accessory tank and fills it. This is done slowly to prevent generation of too much heat. Now shut off the large tank. The pressure gauge now records the pounds of oxygen pressure in the accessory tank and its connections. Connect the oxygen mask to the accessory tank flow and fit the mask to the subject. He receives his oxygen from the accessory tank.
3. Ascend to 20,000 feet. Record the altitude.
4. Refill the accessory tank to say 1500 pounds. Exercise and the stop clock are to be started the instant the pressure gauge needle records 1400 pounds and are to be continued and then stopped the instant the pressure gauge registers 1100 pounds. Record. The metronome should be set to enable the subject to lift the weight 30 times in one minute.

5. Our recording sheet should show;

Altitude	Starting pressure in tank	End pressure in tank	Pounds used	Time in min.
20,000 ft.	1400#	1100#	300#	1.35

6. Then by calculation:
300 pounds of oxygen were used in 1.35 min.
Since there are 3.7 liters of O_2 per 100 lbs. of O_2 at S.T.P.D.; then there are .037 liters of O_2 per 1 pound of O_2 at S.T.P.D.
Therefore: $\frac{300}{1.35}$ = 222.22 pounds of O_2 used/min. at S.T.P.D.
and 222.22 x .037 = 8.22 liters O_2 used/min. at S.T.P.D.

7. By repeating the process the amount of oxygen used at other altitudes for rest or exercise may be determined. The following is taken from such determinations:

	Altitude	Starting pressure in tank	End pressure in tank	Pounds used	Time in min.
Work	5,000 ft.	1300#	700#	600#	1.45
	15,000 ft.	1400#	1000#	400#	1.38
	20,000 ft.	1400#	1100#	300#	1.35
	30,000 ft.	1400#	1200#	200#	1.43
	40,000 ft.	1400#	1300#	100#	1.22
Rest	5,000 ft.	1400#	900#	500#	2.89
	15,000 ft.	1400#	1100#	300#	2.80
	20,000 ft.	1400#	1200#	200#	2.63
	30,000 ft.	1400#	1300#	100#	2.22
	40,000 ft.	1400#	1300#	100#	3.94

It will be found that the pressure gauge needle moves much faster at low altitudes than at high altitudes. As an example, we found that at rest one subject used 500 pounds of oxygen in 2.89 minutes at 5,000 feet, whereas he used only 100 pounds of oxygen in 3.94 minutes while at rest at 40,000 feet. This is because the lowered barometric pressure of high altitudes causes the oxygen to expand in the body where it is no longer under S.T.P.D. This may be noted in studying the tables entitled "Oxygen Flow Needed for BLB Oxygen Inhalation Apparatus." Hence, the pounds of pressure used should be greater at lower altitudes. In order for an individual to use 500 pounds of oxygen resting at 40,000 feet he would have to wait about 20 minutes. As a guide the above table may be used. Let's also note and remember that more pounds of oxygen are used in exercise than in resting since the metabolic rate, circulation rate, etc. are increased in the former.

The amount of oxygen used can similarly be determined if set up for any type of air-oxygen demand. If this air-oxygen demand system is run under similar conditions, both for air-oxygen or straight oxygen, the amount of air added under various conditions can be calculated.

-4-

5. The recording sheet should show:

Altitude	Starting pressure	End pressure	Pounds used	Time in min.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

6. Example of computation:
[illegible] pounds of oxygen were used in 1.25 mins.
There are [illegible] liters of O_2 per 100 [illegible] of O_2 at S.T.P.D., [illegible]
[illegible] liters of O_2 per 1 pound of O_2 at S.T.P.D.
Therefore [illegible] = [illegible] pounds of O_2 used/min. at S.T.P.D.
and [illegible] = [illegible] liters O_2 used/min. at S.T.P.D.

7. By repeating the procedure the amount of oxygen used at several altitudes [illegible] may be determined. The following [illegible] and [illegible]:

Altitude	Starting pressure	End pressure	Pounds used	Time in min.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

It will be found that the pressure [illegible] at low altitudes [illegible] at high altitudes. As an example, we found that at [illegible] of oxygen in [illegible] minutes at [illegible] feet, whereas he used only [illegible] pounds of oxygen in [illegible] minutes at [illegible] feet. Thus we [illegible] the presence of high altitudes [illegible] the oxygen [illegible] at low [illegible] no longer under S.T.P.D. [illegible] Flow demand [illegible] Oxygen [illegible] used should be [illegible] at lower altitudes. [illegible] pounds of oxygen [illegible] as a guide the above table may be used. [illegible] of oxygen are used [illegible] ration rate, [illegible] increased [illegible].

The amount of oxygen used can also [illegible] be determined [illegible] oxygen demand. [illegible] oxygen, the amount of [illegible] may be calculated.

CALIBRATION OF A MAST'R AVIATION FLOW METER USING DETERMINATION OF FLOW RATE BY WEIGHING

A. Equipment.
   1. Accurate balance - reading accurately to 10 mgm. with 5 kgm. weight.
   2. O_2 tank #1 - to be weighed ------/ /-----100 gal. each, or midget emergency tanks.
   3. O_2 tank #2 - not to be weighed -----/
   4. Negative pressure supply - preferable low pressure chamber.
   5. Mercury manometer.
   6. Stop watch or electric stop clock preferably calibrated for tenths and hundredths of a minute.
   7. Bell jar pressure chamber.
   8. Reducing valve for flow meter (to be fitted inside bell jar).
   9. Flow meter to be calibrated (aviation) equipped with mm. graph paper.

B. Apparatus Arrangement.
   1. As in accompanying illustration.

C. Procedure.
   1. Weigh tank #1 - and record.
   2. Run low pressure chamber to highest altitude and keep it there throughout work.
   3. Connect bell jar pressure chamber to low pressure chamber as illustrated.
   4. Connect flow meter to be calibrated to belljar chamber.
   5. Attach O_2 tank #2 to bell jar chamber. Be certain washer is tight at this connection and change it several times during work.
   6. Turn on flow of O_2 tank #2.
   7. Reduce pressure in bell jar chamber until desired altitude is attained on mercury manometer, i.e., 40,000 ft. active (or inactive, if calibrating inactive.)
   8. Set flow meter at the altitude to be checked (same as in #7), i.e., 40,000 ft. active).
   9. Shut off tank #2, and remove it.
   10. Connect tank #1 to bell jar chamber.
   11. Turn on O_2 tank #1 flow and immediately start stop clock as flow meter levels jump.
   12. Let O_2 flow through for at least 5 minutes.
   13. Shut off O_2 tank #1, and immediately watch flow meter levels because tubing of apparatus will contain much oxygen. They will slowly rise and then suddenly drop to zero. Stop the clock at the fraction of a second after they start their final drop.
   14. Disconnect tank #1 and weigh it to get weight change.
   15. Calculate amount of O_2 used per minute at S.T.P.D. which is 760 mm. 0° C. dry.
   16. Sample calculation:
   40,000 feet (active) altitude test conducted at

Weight before test of Tank #1: (On left pan of balance		Weight after test of Tank #1	
Pendulum Left	Swings Right	Pendulum Left	Swings Right
-6.2	+2.9	-11.2	+ .9
-6.2	+2.8	-11.2	+ .9
-6.2	+2.9	-11.2	+ .9

-6.2	-11.2
+2.9	+ .9
-3.3	-10.3

$\frac{-3.3}{2} = -1.65$ $\qquad$ $\frac{-10.3}{2} = -5.15$

-1.65 x .066* = -.109 gms. $\qquad$ -5.15 x .066* = -.340 gms.

* This is the sensitivity of the balance used; = 1 div. = .066 grams.

Weights on Balance:	Weights on Balance:
5000	5000
1000	1000
50	20
20	20
10	1
1	6041.000
6081.00	-.340
-.109	6040.660 gms.
6080.891 gms.	

$$\begin{array}{r} 6080.891 \\ 6040.660 \\ \hline 40.231 \end{array}$$ gms. = Tank Wt. loss after test.

$\frac{\text{Mol. wt. of any gas}}{22.4}$ = Wt. of one liter of the dry gas if the gas is as nearly a perfect gas as is oxygen.

$\frac{\text{Mol. wt. of } O_2}{22.4} = \frac{32}{22.4} = 1.429$ = wt. of one liter of dry O_2 (this figure can be found in physical tables).

$\frac{40.231}{1.429} = \frac{28.153}{5.94}$ (which is time of O_2 flow) = 4.74 liters of O_2 flow per minute through aviation flow meter.

17. A flow of 4.74 liters per minute is found to be sufficient for 40,000 feet active if we consult the charts and tables indicating the required flow of oxygen at various altitudes and under rest or activity.
18. In a similar manner the flow meter is checked for each of the other altitudes marked on its face, both rest and active.
19. If the flow calculated is too high or too low by more than 5 or 10% then one should change the flow accordingly and by use of the graph paper on the flow meter determine the correct level, erase the old marking and paint in the new calibrated marking.
20. Once a flow meter is found to be absolutely accurate then it may be used as a master flow meter and other aviation flow meters may be checked against it by setting both flow meters in the low pressure bell jar chamber and connecting them in series. Then by setting the master flow meter at the desired levels merely note whether the other flow meter levels correspond with those of the master flow meter within allowable limits of 5 to 10%. See the accompanying labeled diagram.

DETERMINATION OF OXYGEN FLOW THROUGH AN AVIATION FLOW METER USING A WET TEST METER

This method is relatively simple in that no weighing is necessary. The prime requisite is to have a standard wet or dry test meter which is accurate; preferably with a 10 liter dial, as a smaller one, such as a 3 liter meter dial, would revolve too fast at altitudes above 30,000 feet. If an issue test meter is not available, then one can perhaps be borrowed from a local gas company. The gas company meters are usually calibrated in cubic feet. One cubic foot is equal to 28.32 liters.

The technique of testing the accuracy of flow of an aviation flow meter is relatively simple and may at times be valuable. New aviation flow meters should be frequently checked, especially if they are for use at high altitudes or in low pressure chambers. After one is convinced by repeated rechecks that an aviation flow meter is, and remains, accurate then it is only necessary to be rechecked again about every 6 months. Knowledge of the technique will undoubtedly be of value at Air Corp stations. First, for accuracy and second, for the psychological effect on the pilot it is well to check his regulator and flow meter before a high altitude flight over 30,000 feet if it is a new regulator or one that he suspects is inaccurate.

The equipment used for the test is as follows:

1. Portable oxygen tank; 100 gallon tank sufficient.
2. Accurate wet test flow meter.
3. Stop watch.
4. Aviation flow meter which is to be calibrated. Flow meter should be fitted with graph paper, i.e. 10 mm. to 1 cm.

Technique for calibration of aviation flow meter:

I. The oxygen tank, aviation flow meter, and wet test flow meter are connected.
II. Check the wet test flow meter and all connections.
III. Ascend in the low pressure chamber to the altitude desired, i.e., 10,000 ft.
IV. Turn the oxygen tank flow on.
V. Set the aviation flow meter at 10,000 feet inactive.
VI. Read the temperature of the wet test flow meter and record.
VII. With the stop watch get the time it takes for 2 complete revolutions of the large dial needle. Six liters is therefore the arbitrary amount for the small 3 L. meter. One may choose to let any number of liters flow through, however, the time should be at least 2 minutes for the flow.
VIII. Assume that 6 liters is allowed to flow through and the time for it is 10 minutes. Assume the barometric pressure at 10,000 feet altitude is 523 mm. Hg and the wet test meter temperature is 25 degrees. The water vapor for 25 degrees temperature is 23.8 (Look up in tables of water vapor).
IX. Calculation:

$\frac{6.0 \text{ liters}}{10 \text{ min.}} = .60$ liters/min. measured at ambient temperature and pressure flowing through the aviation flow meter and wet test meter.

Correcting to S.T.P.D.: (760 mm. 0° C. dry)

$$.6 \times \frac{523 - 23.8}{760} \times \frac{273}{273 + 25} = .6 \times .657 \times .916 = .36 \text{ liters } O_2 \text{ S.T.P.D.}$$

X. Since an inactive man at 10,000 feet requires .50 liters of oxygen per minute - taken from the tables of oxygen requirements using the oxygen apparatus - then the aviation flow meter may be considered as giving slightly less than the required flow at 10,000 feet altitude.
XI. The flow from the aviation flow meter at other altitudes are calculated in a similar manner.

THE WET TEST FLOW METER

I. Preparing wet test flow meter for use:

A. Level the meter by adjusting the leveling screws at the base until the bubble in the spirit level is exactly in the center.
B. Fill the meter with water one or two degrees above room temperature until the water level is slightly above the tip of the pointer in the gauge glass.
C. Make sure all connections are tight.
D. Pass the gas to be measured through the meter until the water is saturated. The approximate volumes necessary at room temperatures under various conditions are as follows: 2 to 3 cubic feet for routine test using the same gas.
E. Disconnect the tubing leading to the meter so that both inlet and outlet are under atmospheric pressure. Draw off water through the small pet cock at the base of the water line gauge until the center of the concave meniscus in the gauge glass coincides exactly with the tip of the pointer.
F. Reconnect the tubing and test again for tightness before proceeding with test.

II. Operation and care of wet test flow meter:

A. The wet test meter is built for operation at a few inches of water column pressure. Excessive pressures will cause the shaft stuffing box to leak and distort the case, producing a bind in the meter which will affect the accuracy. Differential pressures much in excess of .3 inch water column will blow the seal in the meter, causing gas to by-pass the measuring compartments.
B. The water used in the meter, particularly for brass meters, should not be corrosive or contain solids in concentrations high enough to crystallize on the bearings or to alter the density of the water appreciably.
C. Piping connections must not strain or distort the meter case because the bearings will be thrown out of alignment. Care must be taken to preserve the original position of the spirit level, as well.
D. Periodically the meter should be flushed free of sediment, which if allowed to accumulate will reduce the size of the measuring compartments and unbalance the drum. Accumulation of oil on the surface of the water may produce an opposite tendency by creating a false water line within the measuring compartment when the meter is in operation.

WET TEST METER

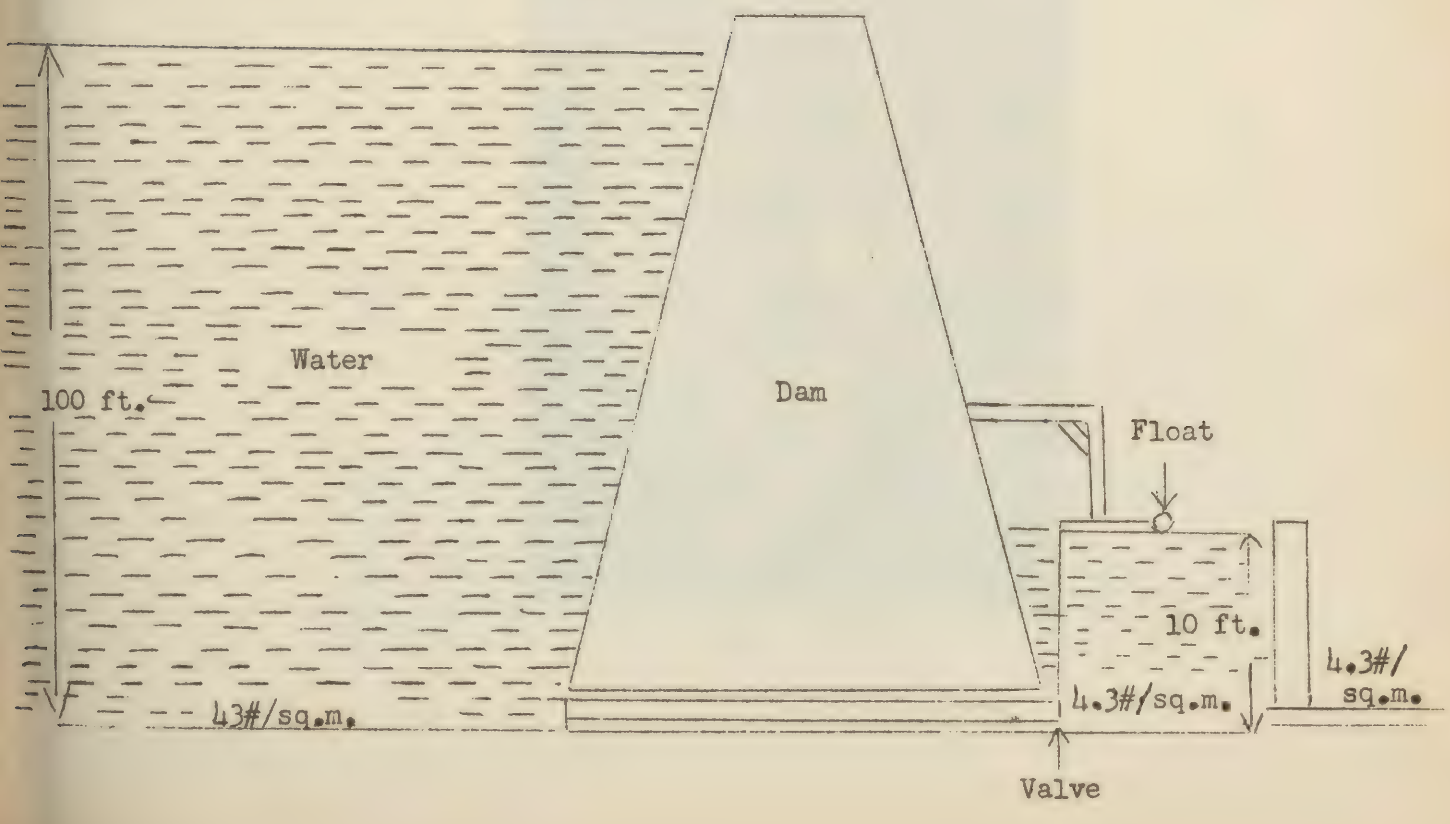
THREE SIZES: 1, 3 and 10 LITERS CAPACITY PER REVOLUTION

THE CONSTRUCTION OF REDUCING VALVES

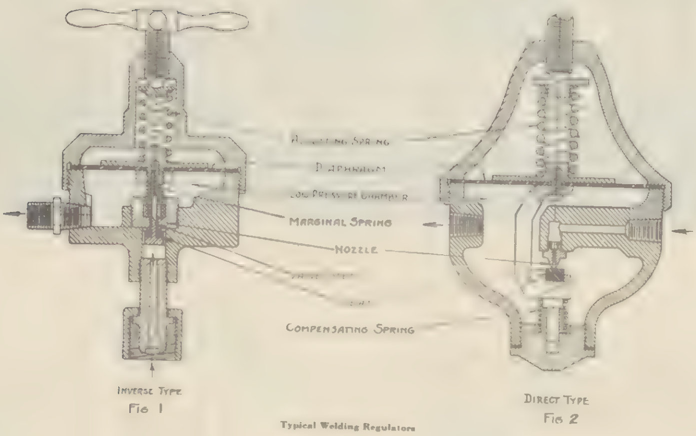
Fundamental requirements

1. The pressure of the gas in the cylinder must be reduced to a low delivery pressure.
2. The delivery pressure must be maintained at a fairly constant value independent of all disturbing influences.
3. Means must be provided to adjust the delivery pressure to any desired level.
4. Maintenance must be reduced to a minimum.
5. The regulator must be safe under all conditions of normal use and as fool-proof as possible.

In considering the principle of the reducing valve, a clearer conception can be obtained by utilizing a more or less homely simile. The water backed up behind a dam is under pressure varying with the depth of the water. The pressure under 33.899 feet of water is equal to one atmosphere (14.7 pounds per square inch). From this it can be calculated that at a depth of 10 feet the pressure is 4.3 pounds per square inch and at 100 feet 43 pounds per square inch.



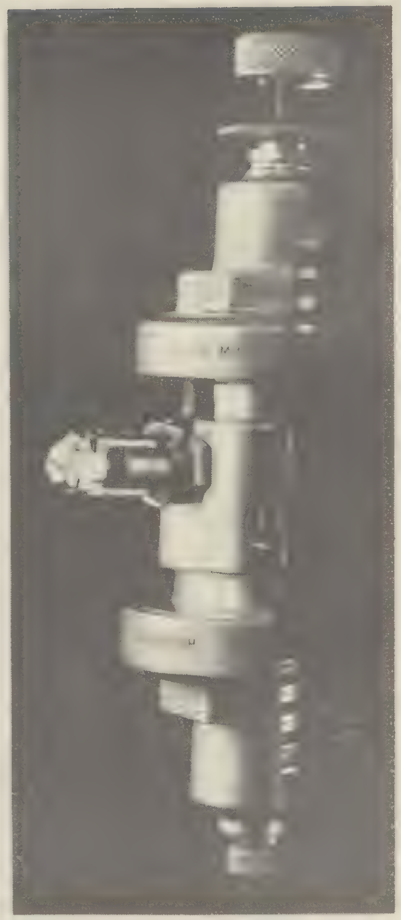
SINGLE STAGE REDUCING VALVE

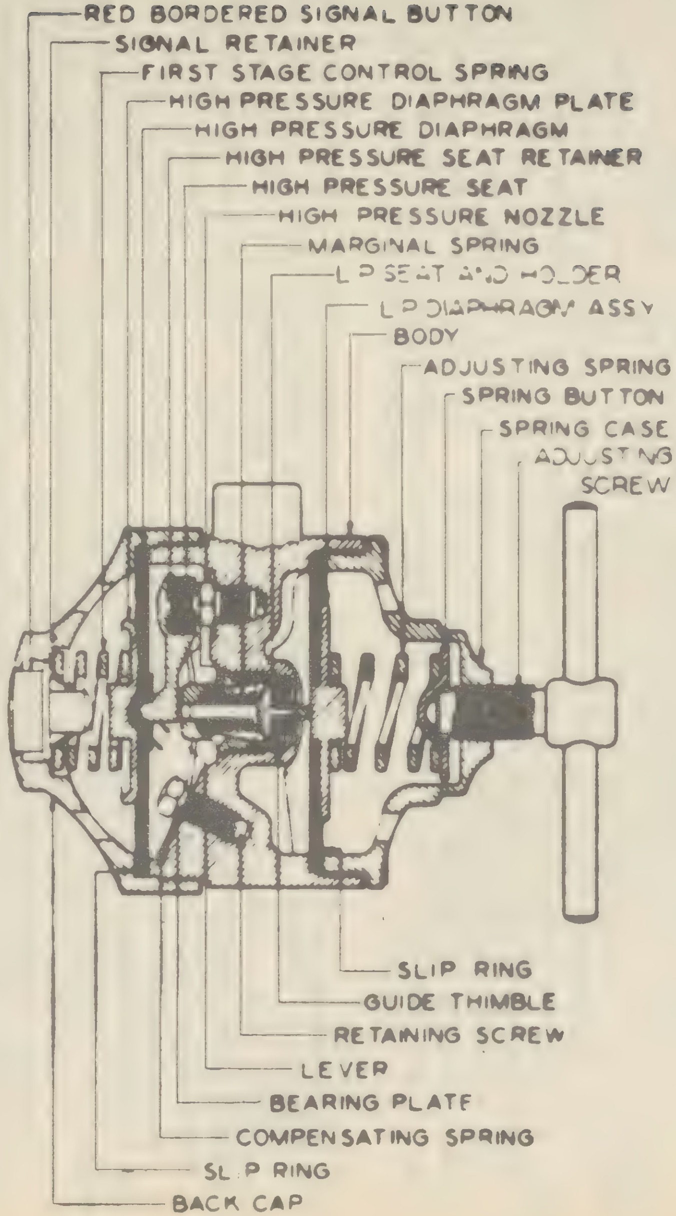


Typical Welding Regulators

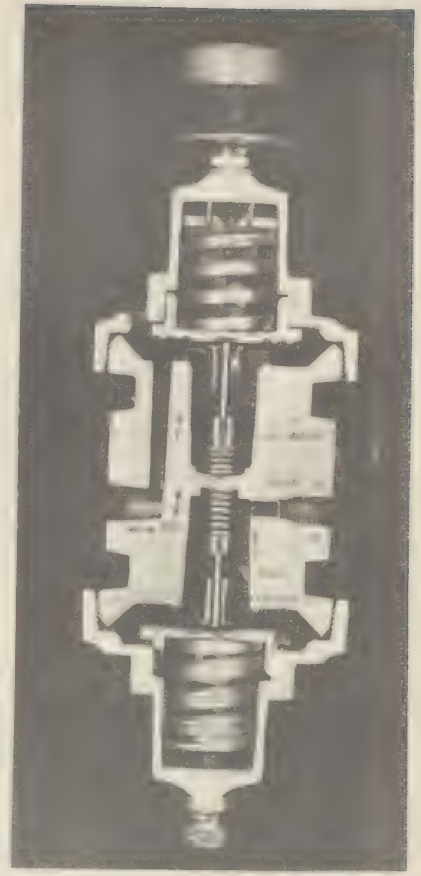
3

Fig. 3





RED BORDERED SIGNAL BUTTON
SIGNAL RETAINER
FIRST STAGE CONTROL SPRING
HIGH PRESSURE DIAPHRAGM PLATE
HIGH PRESSURE DIAPHRAGM
HIGH PRESSURE SEAT RETAINER
HIGH PRESSURE SEAT
HIGH PRESSURE NOZZLE
MARGINAL SPRING
L P SEAT AND HOLDER
L P DIAPHRAGM ASSY
BODY
ADJUSTING SPRING
SPRING BUTTON
SPRING CASE
ADJUSTING SCREW
SLIP RING
GUIDE THIMBLE
RETAINING SCREW
LEVER
BEARING PLATE
COMPENSATING SPRING
SLIP RING
BACK CAP



A pipe is laid at the 100 foot level into the bottom of another pool, as shown in the diagram, and an outlet from the smaller pool made at the level of the pipe (P). A float is arranged 10 feet above the bottom of the smaller pool so constructed that should the water in the smaller pool rise above 10 feet, a valve closes the pipe leading from the dam. Under these conditions the pressure of the water at the inlet of the Pipe is 43 pounds per square inch. The pressure of the water at the bottom of the second pool is maintained at 4.3 pounds per square inch and the pressure of the water in the outlet from the smaller pool is maintained at this same level. This is the fundamental mechanism of the reducing valve. Regulation of the level of the float changes the delivery pressure and the flow through the outlet of the smaller pool just as regulating the adjustment screw of a reducing valve changes the delivery pressure and flow of gas through its outlet tube.

Typical construction of reducing valves is shown in the diagram. The gas enters from the cylinder at the point labeled "inlet." It passes through a valve which throttles the flow of the gas. The diaphragm is a pressure-responsive element which opens the valve slightly in case the pressure falls off, thus permitting an increased flow of gas, reestablishing the pressure. This mechanism works in reverse in case the delivery pressure of the gas increases. The pressure therefore remains quite uniform at any specific setting of the adjustment screw. This adjustment screw increases or decreases the tension on a spring which is transmitted to the diaphragm. If the adjustment spring is under considerable compression, it will exert a relatively heavy thrust against the diaphragm which results in a relatively high delivery pressure. If the tension on the spring is reduced, the delivery pressure is reduced. When the delivery pressure is increased the actual flow of the gas is increased and vice versa.

The amount of flow of oxygen out of a definite-sized orifice produced by a constant setting of the adjustment screw on a reducing valve results in a marked decrease in the rate of flow as the barometric pressure decreases. For example, if one type of reducing valve is set to deliver 3.6 liters per minute at ground level, the actual delivery at 35,000 feet at the same setting of the adjustment screw is only 2.06 liters per minute. This is dependent upon the following two facts. On the outside of the reducing valve, the diaphragm is exposed directly to the atmospheric pressure through holes deliberately made in the case of the instrument because, as a rule, under ordinary conditi   at ground level, change in barometric pressure is negligible. However, in aviation these changes are no longer negligible but become very important because a decrease to one half of the barometric pressure (under standard conditions) on the outside of the diaphragm reduces the pressure from 14.7 pounds per square inch to 7.35 pounds per square inch and similarly for any other change in altitude. Therefore, if no change is made in the adjustment screw which works through the adjustment spring on the outside of the diaphragm, the total pressure on this diaphragm will be decreased, thus reducing the amount of oxygen flow. In one type of two-stage reducing valve this results in a decrease of delivery of oxygen from 3.7 liters per minute S.T.P.D. to 2.1 liters per minute in going from sea level to 35,000 feet altitude.

This is of extreme importance because if the flow of oxygen is set for 35,000 feet while a pilot is at ground level and the rducing valve has no automatic compensator, the pilot will get a progressively decreasing flow of oxygen. Conversely, if the reducing valve is set accurately when the pilot is at 35,000 feet and he descends, there is serious oxygen waste so that his supply of oxygen would last only 2/3 the length of time the supply would last if adequately compensated for altitude.

a [illegible] is [illegible] at the [illegible] level into the throat of another pool, as [illegible] in the [illegible], and an outlet from the [illegible] pool is at the level of the [illegible] [illegible] of the [illegible] the bottom of the smaller pool [illegible] [illegible] [illegible] the [illegible] of the [illegible] pool [illegible] [illegible] [illegible], a [illegible] [illegible] pool [illegible] from the [illegible]. These conditions the [illegible] of the [illegible] of the [illegible] [illegible] pound per square inch. The [illegible] of the [illegible] of the second pool is [illegible] of 0.3 pound per square inch [illegible] [illegible] of [illegible] of [illegible] [illegible] pool is [illegible] [illegible]. [illegible] [illegible] of the [illegible] value. [illegible] [illegible] of the [illegible] [illegible] [illegible] and the flow through the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]. [illegible] [illegible] pressure and flow of gas through the outlet tube.

[illegible] [illegible] of [illegible] [illegible] [illegible] in the [illegible]. The gas [illegible] from the [illegible] of the [illegible] [illegible]. [illegible] [illegible] a [illegible] [illegible] the flow of the gas. The [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] of the [illegible] [illegible]. The pressure [illegible] [illegible] [illegible] [illegible] [illegible] of the [illegible] [illegible]. [illegible] the [illegible] [illegible] be [illegible] the [illegible] [illegible] of [illegible] [illegible] and [illegible] [illegible].

The [illegible] of [illegible] [illegible] [illegible] of a [illegible] [illegible] [illegible] by a [illegible] [illegible] of the [illegible] pound per square [illegible].

[illegible] [illegible].

To prevent the flow of gas when the apparatus is not in use, most types of reducing valves have a spring which completely closes the valve when the tension of the compression spring is completely removed.

With regard to structure there are three types of reducing valves, (1) inverse (or indirect) (2) direct pressure regulators and (3) compound or two state reducing valves in which two regulators are connected in series.

(1) An indirect pressure regulator is one in which the thrust of the high pressure gas is in such a direction as to tend to close the valve seat against the nozzle. (2) A direct pressure regulator is one in which the thrust of the high pressure gas is in such a direction as to tend to force the seat away from the nozzle. (3) The compound or two-stage regulator may be any combination of the above, usually built into a compact unit.

Most pressure regulators (reducing valves) are important because, as the pressure of the tank decreases, the delivery pressure (and flow of the gas) also decreases perceptibly. In glancing at fig. (4) it will be noted that the pressure of the gas from the tank on the valve seat (in the direct type of reducing valve) plus the pressure of the adjustment spring on the diaphragm must balance the pressure of the gas on the diaphragm plus the tension on the compensating spring. In the inverse or indirect type, as the pressure in the tank decreases the delivery pressure increases. To minimize this effect, the area of the diaphragm is large and the diameter of the inlet nozzle, very small. As the pressure in the tank diminishes, it arrives at a point at which the inlet nozzle cannot discharge enough gas to keep up the delivery pressure. This is the regulation end-point for any particular rate of flow. In using the excessively small inlet nozzle, this end point is reached at a higher pressure than is the case with a larger nozzle. The small nozzle, however, will handle a greater load at higher pressures so the size of the nozzle varies with the use to which the regulator is put.

At relatively low levels of cylinder pressure, at points above the regulation end point, the regulating characteristics of any particular reducing valve may markedly change. The effect on the direct type of reducing valve is to markedly reduce the delivery pressure and the flow of the gas. The direct type of regulator in general is more satisfactory if the cylinder pressures are of adequate magnitude. In low pressure units the indirect type of valve is superior.

Other disturbing influences are (1) seat recovery and (2) pre-cooling. When the reducing valve is not in use, the valve seat is tightly pressed against the nozzle, leaving an impression on the rubber or fiber valve seat. If the plastic properties of the material from which the valve seat is made are such that the material tends to continue to change its shape long after the pressure has been removed, the delivery pressure is reduced, rapidly at first and then more gradually. At low rates of flow, the seat recovery is greater than the magnitude of the seat displacement so that the regulator must be constantly watched for a period of an hour or more. This has been cut down markedly by the use of non-hygroscopic seat materials with very rapid recovery values.

When the pressure is rapidly released from a volume of gas, there is considerable refrigeration effect. This may lead to, first, condensation of the small amount of moisture in the gas and later to freezing of the moisture in and about the nozzle. This will also cause marked changes in flow. A satisfactory solution is the two stage reducing valve. In cold weather the first stage of pressure reduction may develop some pressure fluctuations but these will rarely be transmitted through the second stage into the delivery hose.

[illegible]

[illegible] the [illegible] of any [illegible] the [illegible] of [illegible] regulating [illegible] a spring [illegible] the [illegible] of the compression spring is completely removed.

What [illegible] types of reducing [illegible] (a) single-stage regulators and (b) [illegible] two-stage [illegible] of which two regulators are combined in series.

(1) An ordinary pressure regulator is one in which the [illegible] of the high [illegible] pressure [illegible] (2) a [illegible] regulator [illegible] (3) [illegible] two-stage regulator [illegible] compact unit.

Most pressure regulators (reducing valves) are important because, as the pressure of the tank decreases, the delivery pressure [illegible] In [illegible] of Fig. [illegible] the pressure [illegible] the valve [illegible] of the [illegible] the pressure in the tank [illegible] the [illegible] pressure [illegible] the [illegible] of the [illegible] high pressure [illegible]

[illegible] the [illegible] of [illegible] regulating [illegible] the [illegible] pressure [illegible]

[illegible] (1) [illegible] and (2) [illegible] the [illegible] valve [illegible] the pressure [illegible] of the [illegible] the [illegible] pressure [illegible] values.

[illegible] the pressure [illegible] of [illegible] the [illegible] the [illegible] pressure [illegible] the [illegible] from the [illegible]

When two stage regulators are not available, the following precautions must be taken:

1. Do not take oxygen cylinders from a warm room and attempt to use them outdoors in cold weather because until thoroughly chilled, the gases may contain traces of moisture which may block the nozzles of the reducing valve.
2. Operate the regulators at somewhat increased flow over the normal in cold weather.

One other danger involved in the use of reducing valves is what is known as seat ignition. When the compressed oxygen in the cylinder is first turned on, it rushes through the nozzle and strikes the valve seat which is made of some organic material (usually hard rubber). This rapidly compresses the air in the valve chamber and may produce temperatures up to 1700° F. If the valve seat is irregular from use or has inflammable foreign particles on the surface, the presence of such high temperatures in an atmosphere of pure oxygen may cause explosive oxidation of the valve seat. This may indeed be quite dangerous in spite of the presence of safety valves in the apparatus.

Compound regulators are combinations of the direct and indirect type of reducing valves. As indicated above, it is most advantageous to use the direct type of regulator for the first stage in which the pressure may be reduced from 1500-2000 pounds to level of 60-80 pounds per square inch. This level of the first stage reduction is maintained as a constant and the adjustment for varying rates of flow is made on the second stage reducing valve which usually contains an indirect type of valve.

GENERAL RULES FOR HANDLING AND USING OXYGEN EQUIPMENT

A. Oxygen Cylinders:

1. Never place an oxygen cylinder so that it can be knocked down or fall over.

Reasons: (a) If there is a crack in the cylinder wall from previous accidents or from inferior metal in the tank, and the pressure of oxygen in the tank high, the cylinder may explode.

(b) If the valve on the top of the tank is knocked off, the pressure of the oxygen in rushing out may propell the tank about the room like a rocket.

2. Do not store cylinders near inflammable material, especially oil, grease, or any substances likely to cause or accelerate fire.

Reason: Leak of oxygen may raise the oxygen content of the air in the room so that any chance spark from static electricity or short in electrical apparatus may produce a fire or explosion.

3. Oily or greasy substances must never be used in or about cylinder valves, couplings, gauges, hose and connections, especially where high pressure oxygen is to be used. Do not handle oxygen cylinders with greasy hands or gloves.

Reason: Small droplets of film of oil or grease in contact with oxygen in a high pressure system forms a detoning mixture which may explode with violence.

4. Store cylinders in cool dry places.

Reason: Most tanks are equipped with safety devices to allow oxygen to escape if the pressure in the tank becomes too great. The effect of heat is to increase the pressure in the tank so that oxygen is forced out into the room air.

5. Do not expose cylinders to water, snow or rain.

Reason: Threads on the valve caps might rust and make it difficult to remove the caps. The use of grease to prevent rust is, of course, prohibited. (See rule 3).

[illegible]

1. [illegible]
2. [illegible]

[illegible] This may prove to be quite dangerous in spite of the appearance of [illegible]

[illegible] regulations and [illegible] of the [illegible] type of [illegible]

[illegible]

[illegible]

1. [illegible]
   (a) [illegible]
   (b) [illegible]
2. [illegible]

[illegible]

6. Iron Cap over cylinder valve must be kept in place at all times when not in use.
Reason: This protects the cylinder valve from damage in case it is accidentally dropped (See Rule 1).
7. Never use cylinders without a suitable reducing valve or regulator.
Reason: The flow of oxygen cannot be controlled by means of the cylinder valve alone. This may result in great waste of oxygen as well as pouring oxygen into the room air, predisposing any combustible material around the room to rapidly spreading fire.
8. After removing the iron valve cap from the cylinder, carefully crack the cylinder valve for an instant to blow out any dust or particles from the oxygen outlet.
Reason: Particles of dust are large enough to partially or completely clog reducing valves.
9. After adjusting a reducing valve on the oxygen outlet of the cylinder, be sure the adjustment screw on the reducing valve has been released.
Reason: This prevents a sudden flow of oxygen under high pressure through the reducing valve. (See valve seat ignition.)
10. Never permit oxygen to enter the regulator suddenly. Open cylinder slowly.
Reason: (See valve seat ignition.)
11. Avoid using wrenches to tighten cylinder valves.
Reason: Cylinder valves are closed by means of a needle valve. Too severe tightening of the valve may impair the fit of valve and result in leaks in the future.
12. Always open the cylinder valve slowly and continue gradually to completely open it when the cylinder is in use. Leakage about the valve stem occurs if the valve is only half open.
13. Never use a lifting magnet or a rope or chain sling in moving tanks.
Reason: These devices are not secure against dropping the tanks.
14. Do not store full and empty or partially empty tanks together. Before removing a reducing valve from a tank, record in a prominent place the pressure of the oxygen in the tank.
Reason: These precautions protect the flight crews from finding themselves without oxygen at a time when oxygen supply may be vital.
15. If a cylinder is found to be out of order or is suspected of having a crack, mark the cylinder defective and be sure it is returned to the air corps supply.
16. When a cylinder is empty, be sure cylinder valve is closed securely.
Reason: Daily changes in temperature may expand and contract the gas in the tank drawing moisture and room air into the tank. This is known as "breathing" and predisposes to rusting of the needle valve in the cylinder and may result in freezing if the tank is exposed to low temperatures. In addition to this, moisture in the oxygen supply, especially if it is used in oxygen equipment at high altitudes predisposes to freezing of the reducing valves.
17. Before removing reducing valve from the cylinder, always close the cylinder valve securely.
Reason: (see Rules 7 and 17)
18. In filling a small tank with oxygen from a large tank, open the cylinder valve slowly and allow the pressure in the small tank to increase gradually.
Reason: Sudden opening of the valve of the large tank, compresses the gas present in the small tank rapidly enough to generate a great deal of heat.
19. If high pressure oxygen tanks are arranged in series, do not allow the pressure of one tank to fall below the others.
Reason: The effect is the same as in Rule 18.

[illegible]

Seat ignition. The valve seats in cylinder valves and reducing valves are frequently made of organic material such as rubber or fiber. If oxygen at full cylinder pressure is suddenly admitted into a valve, considerable heat may be developed at the valve seat as a result of the heat of compression imparted to the gas which was originally in the regulator inlet passages (as in Rule 18). Since the valve seat is in an atmosphere of 100% oxygen (strictly 99.7%) it requires only a particle of inflammable material on the valve seat to cause an explosive combustion of the valve seat. This is the basis for the repeated rules regarding the careful opening of high pressure oxygen cylinders.

CLOSED CIRCUIT OXYGEN THERAPY APPARATUS - HICO No. 130

General Description

The apparatus is of the closed circuit type and is designed for the economical therapeutic administrations of high concentrations of oxygen up to 100%. Shell natron interposed in the circuit absorbs the carbon dioxide and moisture exhaled by the patient. All sizes of medical and commercial oxygen tanks having standard valve threads may be used, as adapters for each type are included in the equipment.

Assembly

The apparatus as shipped is completely assembled except for a few rubber parts. The method of attaching these is explained. Reference to the accompanying cuts will prove helpful.

Loosen the clamps holding the cover of the carrying case to its base. Turn the cover up-side-down. Place the base containing the apparatus on top of the cover and snap the clamps to place, to elevate the apparatus to convenient working height.

Connect one of the 50" corrugated tubings "25" to the outlet of inspiratory valve "1". Connect the other like tubing "25" to the inlet of expiratory valve "2". Connect the two free ends of these tubings to metal Y connector "3". Attach one end of either the 8" corrugated tubing "4" or 10" corrugated tubing "5" to the base end of Y connector "3" and the other end of this tubing to the connector on the mask.

Attach reservoir rebreathing bag "6" by means of its metal "L" connection "7" to the lower side opening of inspiratory valve "1". (This opening has a rubber connector.)

By means of its union nuts connect tubing "11" tightly to the corresponding threads of oxygen control valve "12" and reducing valve "13".

The union nut of the reducing valve fits the threads of standard large size medical oxygen tank valves. Yoke adapter "10" for small standard medical oxygen tank valves and an adapter having union nut "14" for large standard commercial oxygen tank valves are supplied.

To attach a container of shell natron "16" first remove (pry out) the metal sealing cap from the opening on each side of the container using the screw-driver provided for the purpose. Then position the container in its holder so that gasketed metal Y connection "17" extends into the opening of the container on one side, push gasketed metal L connector "18" against the opposite side of the container and tighten to place moderately with thumb screw of bracket "19".

The apparatus is now ready for use when its reducing valve is attached to a tank.

Description

The supply of oxygen to the patient is delivered by reducing valve "13" having 3000 lb. gauge to indicate tank pressures, through tubing "11" to flowmeter "15". Valve "12" controls the rate of delivery as indicated in liters per minute by the flow meter. Additional emergency volumes of oxygen from valve "19" may be introduced instantly by finger pressure on the valve at "20". Valve "19" when subjected to approximately 2 cm. H_2O negative (inspirational) pressure, also automatically supplies oxygen to the closed breathing circuit. The valve is connected by 8" corrugated tubing "24" to Y connector "17".

Two types of masks are provided. Each mask has straps for attaching to head harness "23" to hold the mask in place on the patient's face.

Harness "23" should be placed on the patient's head with the elastic strap forward and on top. The leather straps are adjustable.

Strap "26" goes around the neck to support the mask tubings and thus relieve strain on the mask.

Expirations pass through the closed circuit in one direction guided by the expiratory and inspiratory valves. Expirations first pass through expiratory valve "2" and by means of 10" corrugated tubing "21" enter and pass through shell natron container "16" for CO_2 and moisture absorption and are conducted therefrom by 8" corrugated tubing "22" to bag "6" and inspiratory valve "1" and thence again to the mask for inhalation.

Valves "1" and "2" may be readily lifted from their grooved suspensions and taken apart (without tools) for ready cleaning.

Whistle "8" warns when the oxygen supply is exhausted or not turned on.

Valve "9) opens automatically to release excessive pressure in the breathing circuit.

Adapters "10" and "14" and reducing valve "13" when not in use should always be screwed onto the studs attached to the inside of the carrying case.

Wrenches for the union nut of reducing valve, adapters and small tank valves are supplied. The screw driver supplied is for uncapping the shell natron container.

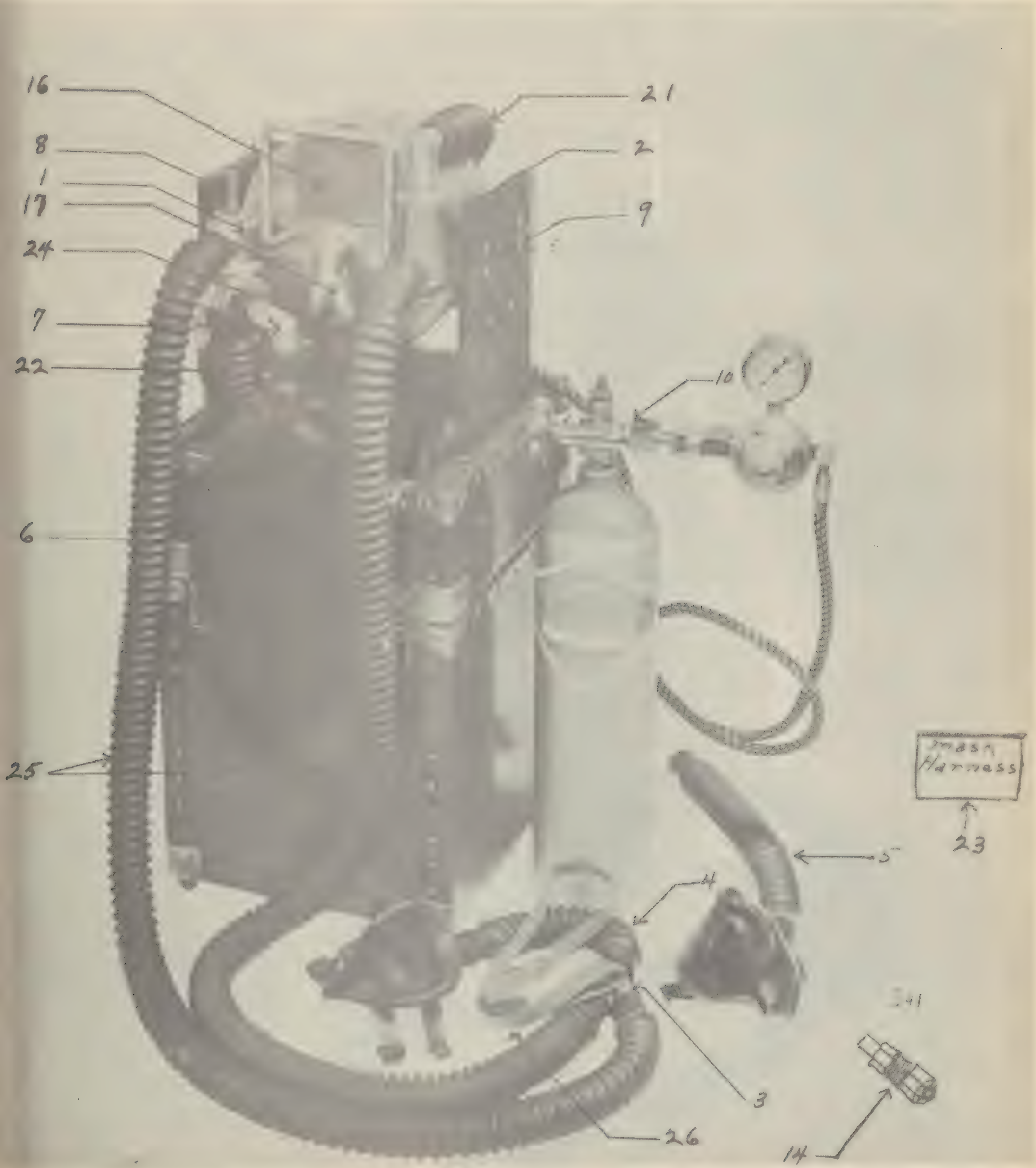
There is a stout handle on the apparatus for lifting.

Operation

Grasp corrugated tubings "25" near the mask and hold them closed tight with the left hand. Open oxygen control valve "12" to about 15 liters flow per minute. When the reservoir-rebreathing bag becomes completely distended, loosen grip on tubings and press the bag to empty it. Repeat this three times, then when the bag is again full apply the mask to the patient's face, reduce the oxygen flow rate to 1 liter per minute and adjust the neck and head harness straps in a manner to retain the mask comfortably in air-tight position. Ask the patient to indicate when he thinks the mask is so adjusted.

With the mask applied the patient is in communication with the closed circuit of the apparatus and is constantly consuming oxygen at the rate of 300 to 400 cc. per minute. Therefore when the oxygen flow is set at 1 liter per minute the supply

OXYGEN THERAPY CLOSED CIRCUIT TYPE FOR FIELD SERVICE



OXYGEN THERAPY CLOSED CIRCUIT TYPE FOR FIELD SERVICE

is more than twice the patient's requirements and should as a rule be sufficient to keep the reservoir bag from collapsing on inspiration even if the mask is not adjusted in absolutely air-tight manner - which it should be. If the bag collapses on inspiration there is leakage around the rim of the mask.

If the bag distends unduly, reduce the rate of oxygen flow to that which just keeps the bag normally distended on expiration and not collapsed on inspiration. In other words there should always be some oxygen-air in the bag. With a cooperative patient and no leaks at the mask about 400 cc. per minute of oxygen will accomplish this. With a non-cooperative patient and mask leakage the oxygen flow rate may have to be more than 1 liter per minute.

The mask should occasionally be removed from the patient's face, the perspiration should be wiped out with a moist cloth and the patient's face should be dried and when possible dusted with talcum powder.

The 8" corrugated tubing "4" provides for less rebreathing and less stimulation by CO_2 than does 10" tubing "5".

A container of fresh shell natron lasts from six to eight hours, depending on the patient. When symptoms indicate, replenish the supply.

Shell Natron

Shell natron absorbs CO_2 and moisture in the average case to an extent sufficient to maintain the carbon dioxide content within the closed circuit of the apparatus normal for six hours (5 hours for large individual) and relative humidity below 30% with the oxygen being delivered at the rate of 1 liter per minute. During the following hour the CO_2 content may rise to as much as $2\frac{1}{2}$ per cent and relative humidity to 80 per cent, both within tolerable limits. With some patients these latter conditions may not prevail until during the next hour.

Using 1 liter of oxygen per minute about one-half the total expired air leaves the apparatus carrying CO_2 and moisture with it. If less oxygen is used the period of usefulness of the shell natron is shortened.

When CO_2 and water are absorbed heat is generated. Most of this however is dissipated by the long respiratory tubings and essentially room temperature and low humidity prevail at the mask.

Shell natron is caustic, will burn the skin and is injurious to fabrics. Therefore care must be exercised in its handling. During use the water collected in the container dissolves the shell natron, forming a strong alkaline liquid. In removing and replacing a container of this chemical DO NOT SPILL.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Determination of Pressure Changes in Masks

Purpose: The oxygen demand regulator, the air oxygen demand regulator and the constant flow types of oxygen equipment depend upon small degrees of pressure differential for their operation. The negative pressure developed during inspiration opens the oxygen valve of both the oxygen demand and air-oxygen demand types. At low rates of oxygen flow in the constant flow type when the bag becomes emptied, air passes into the mask through the sponge rubber discs as long as the negative pressure continues. In the same way it is important to know how much pressure is produced during expiration due to the difficulty with which air passes to the outside. Breathing in the presence of either a high or a low pressure in the mask for any period of time is extremely tiring.

Apparatus: The principle of the Borden tube is utilized in the mechanism used here. It consists of a glass tube with very thin walls in the shape of a horse shoe. As the pressure changes, the tube tends to straighten out. This is recorded by means of a concave mirror which is turned by the movement of the tube. The deviations of the mirror are recorded and magnified by a beam of light which is reflected back to a scale. (See figure) The numbers on the scale are so arranged that if the deviation of the beam of light are noted and this figure is divided by two, the result is the change in pressure in terms of cm. of water.

SENSITIVE PRESSURE RECORDER
THIN GLASS SPOON BORDEN PRINCIPLE
MODIFIED BY BALDES

THIN SPOON SHAPED
GLASS BULB

RUBBER TUBE LEADING
TO PLACE WHERE AIR
PRESSURE IS TO BE
MEASURED

CONCAVE MIRROR SUPPORTED
BY WIRE ACTIVATED BY GLASS
TUBE PROJECTING FROM GLASS
BULB

SLIT LAMP

SMALL TRANSFORMER

METAL BOX CONTAINING
GLASS SPOON

CENTIMETER SCALE

GENERAL SET-UP WITH CENTIMETER SCALE
ARRANGED SO THAT PHOTOGRAPHIC BOX CAN BE SUBSTITUTED

CHIN TYPE CONSTANT FLOW MASK

Alveolar Air Samples

Alveolar air, according to the Haldane School, consists of the specific gas mixture in the lungs which has reached an essential equilibrium with the gas tensions of the capillary blood in the alveolar walls. In this sense it is not limited to the portion of air which fills the alveoli, bu t includes all of the lung air which freely participates in the gaseous exchange and it comprises, therefore, a physiological rather than an anatomical entity.

It is important to know how closely the tensions of the gases in the alveolar air approximate the gas tensions of capillary (arterial) blood since alveolar air samples may be easily obtained while arterial blood sampling is difficult. Carbon dioxide presents no problem as the tensions of this gas in the alveolar air and the arterial blood are nearly identical. During either rest or work the pressure gradient does not exceed approximately 1 mm. of mercury. The oxygen pressure gradient between the alveolar air and the arterial blood also tends to be maintained at a minimal value until the blood is more than 92 per cent saturated.[1]

Since the blood at high altitudes does not ordinarily reach a saturation of 92 per cent, the oxygen tension in alveolar air and in the artery are very closely approximated. At low altitudes, on the other hand, as the oxygen saturation of the arterial blood approaches completion, above 92 to 93 per cent, retardation in the chemical and physical processes within the capillaries may prevent a complete equalization between the oxygen tensions on the two sides of the capillary wall. In addition, technical difficulties in the exact determination of the alveolar P_{O_2} and the estimation of the arterial P_{O_2} from the percentage saturation of the hemoglobin in the upper part of the saturation curve may possibly make an apparent increase in the gradient.

With these facts in mind, the arterial gas tension can be closely approximated if the alveolar gas tensions are known, so long as the pulmonary epithelium is normal in character. This relationship between the gas pressures of the alveolar air and the arterial blood greatly facilitates respiratory research as applied to the problems of aviation, since arterial punctures are technically difficult to perform and are frequently so painful that it is difficult to obtain a sufficient number of voluntary subjects.

In collecting the alveolar air samples not only at ground level but especially in high altitude research, the technic used must be capable of uniformity in both individual and group sampling. The technic also must be relatively simple and foolproof so that a short training of the subjects is all that is required. The Haldane-Priestley method of obtaining alveolar air sample is used in this laboratory. However, the collecting tube is modified as illustrated, and instead of using the tongue to close the proximal end, a special valve has been designed. This valve is so constructed that it instantaneously and automatically snaps shut to trap the alveolar air sample on removing the pressure of the thumb and while open there is a perfectly straight, unobstructed Haldane alveolar air tube which, when making a complete rapid expiration, reduces turbulence in the air stream to a minimum.

Haldane and Priestley usually obtained maximal expirations into the collecting tube after (1) a normal inspiration and (2) a normal expiration and both samples were analyzed and the mean used. However, under many conditions it is only possible to obtain one sample; therefore our averages are based on collections made following only a normal inspiration (see illustration).

---

1. Dill, D. B. and Hall, F. G.: Gas exchange in the lungs at high altitudes, Journal Aeronautical Sciences, 9:220, (1942).

[illegible]

Alveolar air, according to the Haldane school, consists of [illegible] in the lungs [illegible] reached an essential equilibrium with [illegible] of the capillary blood in the alveolar walls. [illegible] the portion of air which [illegible] the alveoli, but it includes [illegible] of the lung air which [illegible] particularly in the [illegible] and it comprises, therefore, a [illegible]

It is important to know how closely the [illegible] of the gases in the alveolar air [illegible] the gas tensions of capillary (arterial) blood [illegible] blood sampling is difficult. [illegible]

Since the blood at high altitude does not [illegible]

[illegible]

In collecting the alveolar air sample not only [illegible]

[illegible] and Priestley usually [illegible] (1) a normal inspiration and (2) a normal expiration [illegible] However, under [illegible]

---

[1] [illegible]: Gas Exchange in the Lungs at High Altitude. [illegible]

The following is a more detailed description of the method used in this laboratory. The glass sampling sets have been described in the section on the "Haldane Gas Analysis Apparatus." The large glass cylinders (175 cc.) must be used for alveolar air samples at high altitudes while the standard size (45 cc.) is adequate for samples obtained at sea level or low altitudes. Each sampling set and each tube in the set is numbered. The lowest numbers should be used first and complete records kept.

Before taking a sample the mercury level in the glass sampling tube must be checked. The mercury should completely fill the cylinder and the glass tube extension above the stopcock, The short length of small-bore (1 to 1.5 mm.) rubber tubing attached to the side of the collecting tube is then connected to the glass tube extension of the glass sampling cylinder. Just before the alveolar air sample is obtained, the mercury reservoir on the sampling set should be lowered, with the upper stopcock closed. Above 25,000 feet this produces a vacuum within the glass cylinder of the sampling set, and facilitates a rapid transfer of the alveolar air sample to the glass sampling cylinder. To obtain an instantaneous or so-called evacuated sample at ground level, the level of the mercury in the reservoir would have to be lowered to nearly 3 feet below the sampling set and the stopcock (if present) at the bottom of the sampling tube closed.

To collect an alveolar air sample, the subject at the top of a normal inspiration makes a rapid maximal expiration into the mouthpiece of the modified Haldane alveolar air collecting tube while holding the perpendicular cylindrical valve open with the thumb. As soon as the maximal expiration is completed, the subject immediately releases the valve; this action closes the orifice to the mouthpiece. The subject's mouth is removed from the metal mouthpiece only after the valve has snapped back into the shut-off position. When the valve is closed, the assistant immediately opens the stopcock (vertical position) of the glass sampling cylinder, the mercury reservoir having previously been lowered to the base of the sampling set. The vacuum produced in the glass sampling cylinder by lowering the mercury permits the last part of the alveolar air which was expired into the collecting tube to pass into the glass sampling cylinder. The assistant then closes the stopcock at the top of the galss cylinder and brings the mercury reservoir to its normal position at the top of the sampling set. The alveolar air sample is thus safely collected in the glass sampling cylinder and it is maintained at a positive pressure by the position of the mercury reservoir so that if leaks occur around the stopcock the sample will be lost instead of diluted by room air. After a little experience the whole procedure can be carried out in from five to ten seconds. The subject should be required to give consistent alveolar carbon dioxide determinations before using him for investigation of a problem; as a rule we require here a preliminary series of eight consistently normal alveolar carbon dioxide and oxygen determinations.

If any type of mask is used, a carefully arranged routine should be worked out so that just before obtaining the alveolar air sample, the straps holding the mask in place should be unfastened by the assistant with the subject holding the mask in place with his left hand; he should have the alveolar air tube in his right hand with the thumb holding the spring valve open. He then at the end of a normal inspiration removes his mask with his left hand and instantly puts the alveolar air tube in his mouth, gives the quick maximal expiration, closes the valve by removing his thumb, lowers the alveolar air tube and with his right hand puts his mask on his face and breathes normally; the assistant fastens the mask straps. At high altitudes, 35,000 to 42,000 feet, only those thoroughly trained in

The following is a more detailed description of the methods used in [illegible] experiments. The plant materials have been described in the section on [illegible] [illegible] [illegible] and complete [illegible].

[illegible]

To collect an aliquot [illegible] sample [illegible]

If [illegible]

the routine both as subject and assistant should carry out this procedure, since with trained personnel there is no danger. The need for precision and economy in motion in these procedures at high altitudes can be more fully appreciated when it is realized that the subject has approximately only 35 seconds of consciousness when breathing the ambient air at 35,000 feet and above.

Normal alveolar air at sea level has the following composition: carbon dioxide varies between 4.7 and 6.1 per cent (usually about 5.6 per cent) or from 34 to 43 mm. Hg pressure; oxygen per cent varies from about 13 to 15 per cent (usually 14.6 per cent) or from 93 to 107 mm. Hg pressure (usually about 104 mm.). However in aviation, values between 80 and 120 mm. can be considered normal. The balance is nitrogen and water vapor. In the Haldane analysis the cancelling out of the water vapor results in a determination which is based on dry air.

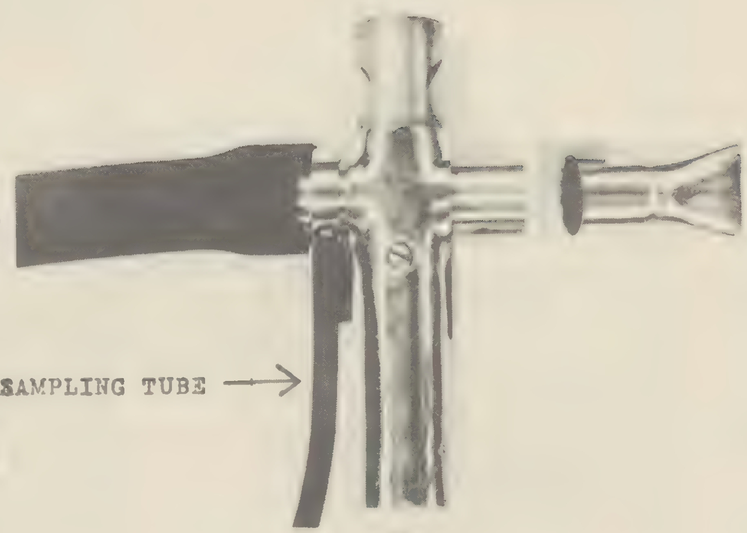
To calculate the tension or pressure of the gases in the alveolar air from the percentage composition, we first determine the barometric pressure which is the total pressure exerted by all the gases including water vapor in the alveolar air. The barometric pressure will average 760 mm. Hg at sea level. Since alveolar air is saturated with water vapor at body temperature, 37° C., the partial pressure of the water vapor will always be 47 mm., therefore this value must be subtracted from the total pressure. Thus, 760 - 47 = 713 mm. Hg will be the total pressure of the dry gases, carbon dioxide, oxygen and nitrogen and the partial pressure of each will be (B - 47) multiplied by the fraction representing the percentage found by analysis, thus:

the CO_2 pressure is $\frac{5.6}{100} \times 713 = 40$ mm. Hg

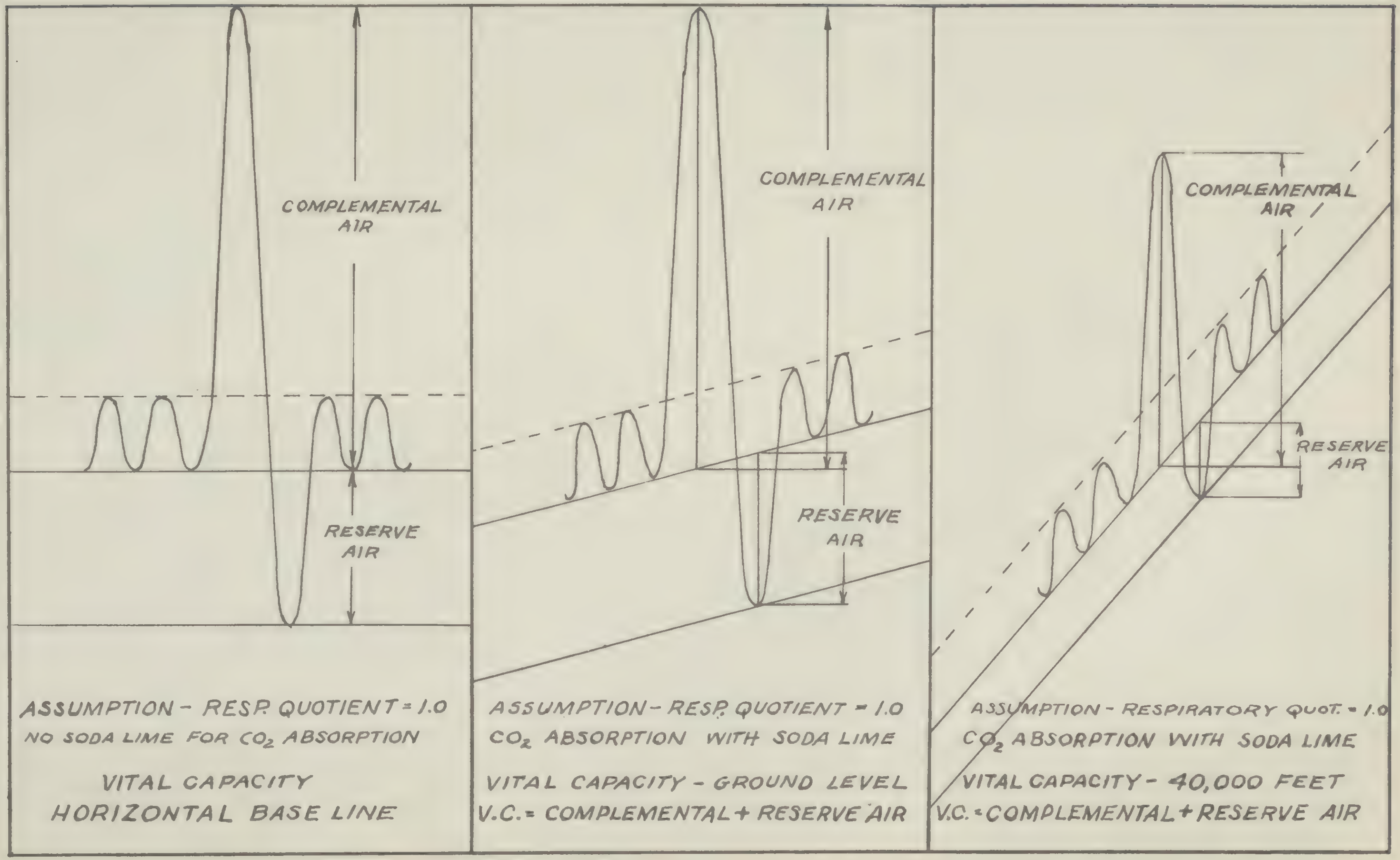
the O_2 pressure is $\frac{14}{100} \times 713 = 100$ mm. Hg and

the N_2 pressure is $\frac{80.4}{100} \times 713 = 573$ mm. Hg (N_2 includes the rare inert gases).

THE MODIFIED HALDANE ALVEOLAR AIR SAMPLING TUBE



VITAL CAPACITY
METHOD OF MEASUREMENT



MAJ. H.A. ROBINSON, MC
F.J. ROBINSON, M.D. SEPT. 1943

XIX - 2 b APPENDIX FIG. II

MAYO AERO MEDICAL UNIT

INDOCTRINATION PROGRAM

OUTLINES AND LECTURES FOR BEGINNING AND ADVANCED
AIR CORPS PERSONNEL

First Edition prepared by

Captain M. Robert Halbouty
Medical Corps, U. S. Army

and

Captain Joseph A. Resch
Medical Corps, U. S. Army

While assigned to
MAYO AERO MEDICAL UNIT
Walter M. Boothby, M. D., Chairman

First Edition - January 1942
Second Edition - August 1942

LECTURE OUTLINE FOR INSTRUCTORS
OF BEGINNING AVIATION CADETS

Concerning

FLIGHT PROPHYLAXIS

Equipment: I. Proper charts showing barometric changes with altitude, the anatomy of the ear, physiology of a blackout, etc. 2. Blackboard. 3. Various types of oxygen equipment, i.e., masks, tanks, regulators, etc. 4. Motion pictures.

Time: Approximately one hour.

I. Introduction.
  A. Relation of aviation medicine to flying.
  B. Responsibilities of flying officers.
    1. To selves.
    2. To crew.
    3. To passengers, i.e., wounded.

II. The Atmosphere.
  A. Definition.
  B. Atmospheric pressure.
    1. Definition.
    2. High altitude; thin air; decreased atmospheric pressure.
  C. Composition of atmosphere.
    1. By volume.
      a. Nitrogen 78%; roughly 4/5.
      b. Oxygen 21%; roughly 1/5.
      c. Rare gases 1%.
    2. Partial pressure.
      a. Definition.
      b. Variability with altitude.
      c. Effect on available amount of oxygen.
  D. Flight Surgeon's division of the atmosphere.
    1. Upper limit of unimpaired performance; 10-11,000 feet.
      a. Individual variability.
      b. "Physiological zone" of the atmosphere.
    2. Critical limit; 20,000 feet.

III. Effects of Lack of Oxygen.
  A. Organs effected.
    1. Brain and nervous system; very susceptible.
    2. Heart.
    3. Muscles, etc.
  B. Amount and extent of body changes.
    1. Dependent on following factors: (Assuming a healthy man).
      a. Altitude attained.
      b. Duration of lack of oxygen.
      c. Flight frequency.
  C. Individual factors varying reactions to a lack of oxygen.
    1. Natural ability.
    2. Physical activity.
    3. General physical condition.

D. Subjective symptoms.
   1. Unawareness of the progressive effects of decreasing oxygen pressure (increased altitude).
   2. Pulse rate increase; compensatory.
   3. Surprisingly little increase in depth or rate of respiration.
   4. Euphoria.
   5. Poor judgement with mental and physical response.
   6. Dizziness.
   7. Unconsciousness.
   8. Accessory symptoms.
      a. Pain in ears, sinuses, etc.
         To be discussed later.
   9. Headache and fatigue on recovery.

IV. Use of Oxygen During Flight.
A. Advantages.
   1. Prevention of oxygen lack; prophylactic - even at low altitudes.
B. Precautions.
   1. Complete equipment check before flight.
   2. Avoid flames.
   3. Avoid oils or grease on any metal oxygen connection.
C. Equipment.
   1. Oxygen tanks; demonstration.
   2. Regulators; demonstration.
   3. Tubing; demonstration.
   4. Masks; demonstration.
      a. Proper fit.
      b. Explanation of mask principle.
D. When to use in flight (A.R.)
   1. 10-12,000 feet; 6 hours or more.
   2. 12-15,000 feet; 2 hours or more.
   3. 15,000 feet and higher; always.
   4. All night flying.
   5. Lower altitudes if low individual altitude tolerance present.
E. Misconceptions concerning oxygen.
   1. Effect on teeth and fillings.
   2. Effect on lungs.
   3. Inflamability; (one drop of oil makes high pressure oxygen an explosive.)

V. Relation of Physical Condition to Oxygen Requirements.
A. Lack of sleep and exercise.
B. Improper diet.
C. Drugs and alcohol.
   1. Sedatives.
   2. Headache powders.
   3. Sulfonamids.
   4. Excessive tobacco.
   5. Alcohol.

VI. Barometric Pressure Changes in the Ear.
  A. Ear anatomy; brief.
  B. Ascent.
    1. Effect on tympanic membrane.
      a. Eustachian tube opened.
      b. Eustachian tube closed.
  C. Descent.
    1. Effect on tympanic membrane.
      a. Eustachian tube opened.
      b. Eustachian tube closed.
  D. Symptoms of "ear block."
    1. Fullness in middle ear; "stuffy."
    2. Varying degrees of hearing loss.
    3. Head noises.
    4. Pain.
    5. Vertigo.
    6. Rupture.
  E. Prophylaxis.
    1. Yawning, singing, shouting.
    2. Swallowing; mints or chewing gum.

VII. Barometric Pressure Changes and the Sinuses.
  A. Brief anatomy.
  B. Ascent.
    1. Sinuses open.
    2. Sinuses obstructed.
      a. Symptoms.
  C. Descent.
    1. Sinuses open.
    2. Sinuses obstructed.
      a. Symptoms.
  D. Treatment.
    1. Benzedrine inhaler. (Caution:)
    2. Correction of cause of obstruction.

VIII. Barometric Pressure Changes and Intestinal Gases.
  A. Physiology of expansion of gases.
    1. Toy balloon illustration.
    2. Volume increased nearly $5\frac{1}{2}$ times at 35,000 feet.
  B. Symptoms.
    1. Distention, discomfort, cramps.
    2. Dyspnea, cardiac embarrassment.
  C. Treatment.
    1. Abdominal massage with belching and passing of flatus.
    2. Powdered charcoal tablets orally.
  D. Prophylactic diet.
    1. Avoid beans, cabbage, peas, beer, carbonated drinks.
    2. Avoid constipation.

IX. Hyperventilation; to be avoided.
  A. Definition.
  B. Symptoms.
    1. Dizziness.
    2. Rapid pulse.
    3. Perspiration.
    4. Claminess.
    5. Visual disturbances.
    6. Judgment errors.
    7. Muscular spasms.
    8. Unconsciousness.
  C. Causes.
    1. Anxiety.
    2. Fear
    3. Panic.
  D. Treatment.
    1. Holding breath.
  E. Demonstration using six class members.

LECTURE FOR BEGINNING AVIATION CADETS

Material Required: 1. Proper charts showing barometric changes with altitude, the ear anatomy, physiology of a blackout, etc.
2. Blackboard.
3. Various types of oxygen equipment.
4. Moving pictures.

Time Required: Approximately one hour.

I. Introduction

A. Relation of aviation medicine to flying.

Without aviation medicine and flight surgeons aviation would probably not have progressed to its present advanced stage. Probably no other occupation requires as great a degree of coordination between mind and body as does aviation. In addition to carrying on their duties of selecting favorable men for pilots and maintaining the health and value of the older pilots, the flight surgeons and civilian physicisns have done commendable work in attempting to make the human machine as fit as the mechanical machine by continuous experimentation and research.

The Collier Trophy which, as you know, is awarded to those individuals or organizations who have contributed most to the progress of aviation was given, in 1941, to three physicians. Two of these were civilians and one was an army flight surgeon.

B. Responsibilities of flying officers.

Perhaps the greatest reason for this lecture is to make you fully realize some of the dangers of flying and to inform you as to the protective measures you should use to combat these dangers - in short, flight "prophylaxis." The pilots and crews of combat planes are highly trained individuals. It is your responsibility to take proper care of all the men who are dependent upon you, not only the crew but also in many instances the sick and wounded passengers. You must understand the dangers involved in high altitude flying and all the methods used for maintenance of the safety and efficiency of the human machine in the air. You must understand not only the mechanical phases of flying but also be able to thoroughly instruct and supervise your crew and to transport with safety any casualties, or wounded passengers assigned to you for evacuation. Problems that may confront you later may be as follows: How high should I fly with a passenger ill with pneumonia? How rapidly may I descend with a passenger having severe injuries with shock? What stops must I and my crew take in order to avoid a lack of oxygen at high altitudes?

II. The Atmosphere.

A. Definition.

The atmosphere may be defined as the layer of air surrounding the earth. This layer of air is approximately sixty-two miles thick (327,360 feet).

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

B. Atmospheric pressure.

This layer of air (the atmosphere) has mass and weight, and its weight or pressure exerted on the earth's surface at sea level is known as the "atmospheric pressure" at sea level. The air layers nearest the earth's surface are pressed on by the air layers above so that the air at lower altitudes is more dense and under greater pressure than those at higher altitudes. Thus, the higher the altitude, the "thinner" the air and the lower the barometric pressure. To illustrate this, if we have a pile of duck feathers uniformly mixed with chicken feathers, the feathers at the bottom of the pile are more compressed than those at the top, and a cubic foot of feather mixture from the base of the pile will contain more feathers than a cubic foot taken from the top. However, the percentage of each kind of feathers will be the same. The barometric (or atmospheric) pressure at sea level under standard condition is 760 mm. Hg - that is, it is equal to the pressure a column of mercury 760 mm. high would exert. This figure (760 mm. Hg) may also be expressed as 29.9 inches of mercury.

C. Composition of atmosphere.

1. By volume.

By volume, the atmosphere is composed of 78 per cent nitrogen, 21 per cent oxygen (more accurately 20.93 per cent), a small amount of carbon dioxide (CO_2 = 0.03%) and traces of rare gases make up the balance of about 1 per cent. Roughly, therefore, the air is composed of 4/5 nitrogen and 1/5 oxygen.

2. Partial pressure.

According to Dalton's law, the partial pressure of a specific gas in mixture of gases is the pressure exerted by the specific gas only - that is, the pressure that the specific gas would exert if it alone occupied the space of the whole gaseous mixture. Since oxygen composes 21 per cent of the atmospheric air, then at sea level the partial pressure of oxygen is 21 per cent of 760, or 159 mm. Hg. Partial pressures are important, especially that of oxygen, for it is the partial pressure that forces oxygen through the walls lining the air sacs of the lungs into the blood and from there it is transported to the tissues. Since the barometric pressure decreases with increase in altitude, the partial pressure of oxygen also decreases so that at higher altitudes less oxygen is driven into the blood from the lungs.

D. Flight Surgeon's division of the atmosphere.

For beginners in flying it is probably only necessary to divide the atmosphere in a rough manner, using the flight surgeon's division; that is, first, the upper limit of unimpaired performance, which is at an altitude of 10,000 to 11,000 feet, and, second, the critical limit which is at 18,000 to 20,000 feet. Ten to eleven thousand feet is set as a limit because most individuals can fly at these altitudes for several hours without undue fatigue or effect on the body. However, some individuals have less resistance even for a small lack of oxygen. They may experience symptoms of lack of oxygen after several hours of flying at only 8,000 feet during a period of days. At the critical limit of 18,000 to 20,000 feet danger of unconsciousness and death is even present without additional oxygen. Any flight for any length of time at 15,000 feet or more must be made with the help of additional oxygen.

1. Atmospheric pressure.

This layer of air (the atmosphere) has mass and weight, and its weight or pressure exerted on the earth's surface at sea level is known as the "atmospheric pressure" at sea level. The air layers nearest the earth's surface are pressed on by the air layers above so that the air at lower altitudes is more dense and under greater pressure than that at higher altitudes. Thus, the higher the altitude, the "thinner" the air and the lower the barometric pressure. To illustrate this, if we make a pile of duck feathers uniformly mixed with chicken feathers, the feathers at the bottom of the pile are more compressed than those at the top, and a cubic inch of feathers taken from the base of the pile will contain more feathers than a cubic foot taken from the top. However, the percentage of each kind of feathers will be the same. The barometric (or atmospheric) pressure at sea level under standard conditions is 760 mm. Hg - that is, it is equal to the pressure a column of mercury 760 mm. high would exert. This figure (760 mm. Hg) may also be expressed as 29.9 inches of mercury.

C. Composition of atmosphere.

1. By volume.

By volume, the atmosphere is composed of 78 per cent nitrogen, 21 per cent oxygen (more accurately 20.95 per cent), a small amount of carbon dioxide (CO_2 = 0.03%) and traces of rare gases make up the balance of about 1 per cent. Roughly, therefore, the air is composed of 4/5 nitrogen and 1/5 oxygen.

2. Partial pressure.

According to Dalton's law, the partial pressure of a specific gas in mixture of gases is the pressure exerted by the specific gas only - that is, the pressure that the specific gas would exert if it alone occupied the space of the whole gaseous mixture. Since oxygen composes about one fifth of the atmospheric air, then at sea level the partial pressure of oxygen is 21 per cent of 760, or 159 mm. Hg. Partial pressures are important, especially that of oxygen, for it is the partial pressure that forces oxygen through the walls lining the air sacs of the lungs into the blood and from there to the tissues. When the barometric pressure [illegible] the partial pressure of oxygen is [illegible] that is forced [illegible] blood from the lungs.

D. Flight Surgeon's divisions of the atmosphere.

For purposes in flying it is probably only necessary to divide the atmosphere in a rough manner, using the flight surgeon's divisions; that is, first, the lower limit of unimpaired performance, which is at an altitude of 10,000 to 11,000 feet, and second, the critical limit which is at 18,000 to 20,000 feet. Up to the lower threshold that is up to 10,000 feet [illegible] flight these altitudes for several hours without undue fatigue or effect on the body. However, some individuals have lost performance even for a small lack of oxygen. They may experience symptoms of lack of oxygen after several hours of flight at only 8,000 feet during a period of years. At the critical limit of 18,000 to 20,000 feet dangers of unconsciousness and death are present without additional oxygen. Any flight for any length of time at 10,000 feet or more must be made with the use of additional oxygen.

Without additional oxygen, an average individual can carry on efficiently during the following lengths of time at the following altitudes:

35,000 feet - about 35 seconds
25,000 feet - about 5 minutes
20,000 feet - 10 to 15 minutes
18,000 feet - 45 to 75 minutes
15,000 feet - 5 to 6 hours
10,000 feet - all day, but symptoms of chronic oxygen lack will be present if repeated daily.

A very important figure to remember is 35 seconds at 35,000 feet before the subject becomes completely unconscious if making an attempt to get out of an airplane; he would last a few seconds longer if he sat quietly and held his breath. Breathing air after the oxygen has been out off or stopped washes out the enriched mixture so that with exercise and breathing the aviator will last only about seven or eight breaths at 35,000 feet and a shorter time if at a higher elevation. Should he sit quietly and hold his breath, he would last a few seconds longer.

III. Effects of Lack of Oxygen.

Increase of altitude (decrease in atmospheric pressure) will result in the following effects on the human body:

1. altitude sickness due to lack of oxygen (anoxia)
2. effects due to decreased pressure such as the expansion of gases in the abdomen and in the middle ear, and also aero-emphysema and aeroembolism
3. effect of cold
4. airsickness, which is due to the motion of the ship and is similar to seasickness.

In considering the effects of lack of oxygen special stress is to be put on some of the organs affected. The brain and nervous system are very susceptible to even small amounts of oxygen lack. The heart, muscles, and other parts of the body are also affected. The amount and extent of body changes are dependent on the following factors, assuming that we have a healthy man:

1. Altitude attained, since the higher the altitude, the less is the availability of oxygen to the body.
2. The duration of the lack of oxygen, since the longer the duration the more changes there are.
3. The frequency of flight. Repeated trips on successive days to altitudes producing only very slight lack of oxygen will, if frequently repeated, (as daily for a month) cause definite symptoms of impaired mental and physical functions.

There are several individual factors which affect responses to a lack of oxygen. These are natural ability, physical activity and general physical condition. Some individuals have a natural ability to show little change to moderate amounts of oxygen lack - that is, they have a high resistance to lack of oxygen; their symptom threshold is high. This was important in the previous

war when ability to go to 20,000 feet made you superior in fighting an enemy that could only go to 18,000 feet. Today this difference is insignificant because with proper equipment you can go to 33,000 feet and be normal and can reach 42,000 feet as safely as you could formerly reach 20,000 feet, as far as oxygen is concerned. Increased physical activity stimulates body metabolism and oxidation so that more oxygen is needed by the body, and if the additional supply of oxygen is not received, then symptoms of oxygen lack set in earlier and are more severe than if the body were at rest. An individual in good general physical condition almost invariably reacts less to the same amount of oxygen lack than does one in poor physical condition, assuming everything else to be equal.

There is surprisingly little awareness of the progressive effects of decreasing oxygen pressure. There is usually a compensatory increase in the pulse rate, but only a little increase in depth or rate of respiration. Euphoria (a false sense of well-being) and poor judgment with poor mental and physical response are usually followed by dizziness and unconsciousness with possible disastrous results. Should consciousness be regained, headache and marked fatigue will be noted. Accessory symptoms, as earache, will be discussed later.

IV. Use of Oxygen During Flight.

A. Advantages.

The one big advantage in using additional oxygen during flight is that by so doing one prevents an oxygen lack, a simple, but important fact. Benefits of oxygen administration may be summed up in the one word - "prophylactic." It is prophylactic against symptoms of oxygen lack even at low altitudes.

B. Precautions.

Before attempting to use oxygen we should become familiar with a few of the precautions we should use. First, and perhaps of most importance, is a habitual complete check of oxygen equipment before each flight. Either you or someone you are certain is a responsible individual should make the check. Avoid flames! Oxygen makes things more inflammable. Last, but not least, avoid using oils or grease on any metal oxygen connections. Oils and high pressure oxygen can result in an explosion! Warn your mechanics.

C. Equipment.

Here you see some of the various oxygen tanks used by the Army. (Short discussion of the characteristics of the various tanks, i.e., low pressure, high pressure, etc. and discuss tank poundage and refilling and necessity for using dry oxygen.)

Here, gentlemen, we have some of the various types of oxygen regulators in use. These (deomonstrate) are the hand controlled type and should be set at about the altitude at which one is flying if sitting quietly and 5,000 feet higher if exercising. Some flow meters are correctly marked on one side for "resting" flow and on the other side for use if the aviator is "active"; that is, using his muscles by working. These (demonstrate) are the demand types

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

which supply oxygen according to the demands of the body. They are automatic and will supply more oxygen at higher altitudes or while the individual is active instead of resting. There are two types of demand regulators. One type mixes the necessary amounts of air and oxygen, and is best suited to altitudes under 30,000 feet. The other type supplies only oxygen with no added air and therefore is wasteful of oxygen at altitudes below 30,000 feet. These will now be passed around for your inspection. Please handle them with care.

The tubing before you is used in connecting the oxygen apparatus. (Short talk and demonstration.)

One of the most important parts of our oxygen equipment is the oxygen mask, based on two different principles, (1) the constant flow principle with reservoir rebreathing bag and (2) the demand principle. Recently these two principles have been combined so as to obtain the advantages of both without the disadvantages of either. (The various types will be demonstrated by the lecturer and much emphasis placed on the aviator's understanding his equipment and the necessity of taking proper care of it.)

Army regulations regarding use of oxygen in flight are as follows: When

1. An altitude of 10,000 to 12,000 feet is contemplated for six hours or more.

2. An altitude of 12,000 to 15,000 feet is contemplated for two hours or more.

3. An altitude of 15,000 feet or higher is contemplated for any length of time.

In addition, all night flying is to be done with oxygen, since even small amounts of oxygen lack may interfere with night vision. Any individual with low altitude tolerance should not hesitate to use oxygen at lower altitudes than those specified above.

Before leaving oxygen I wish to correct some misconceptions concerning oxygen. Oxygen as used today has absolutely no deleterious effect on the teeth or fillings and none on the lungs even if used repeatedly for hours. As a matter of fact, oxygen is used in the treatment of pneumonia, heart disease, and many other medical conditions. And let's not forget that oxygen is inflammable, and that high pressure oxygen, in contact with oils or grease will explode. There is no such thing as "medical oxygen." For hospital use the outside of the tanks are more often repainted and the valves more frequently changed. In aviation, however, for high altitude flying or in planes relatively unheated, dry oxygen must be used, otherwise the water the oxygen contains may freeze on the needle point of the reducing valve. If this freezes the aviator will be suddenly deprived of his oxygen supply.

V. Relation of Physical Condition to Oxygen Requirements.

There is a definite relation between one's physical condition and the harmful effects of oxygen lack; his "ceiling" is lowered. Lack of sleep makes us more susceptible to the effects of oxygen lack, especially if continued over a period of weeks or months. Your grammar school teacher's advice about getting eight or ten hours of sleep nightly still holds good. As stated already, one's general physical condition is one of the factors determining reaction to a lack of oxygen. The worse

valve supply oxygen according to the demands of the body. They are automatic and will supply more oxygen at higher altitudes so that the individual is [illegible] of altitude. There are two types of demand regulators [illegible] the necessary mixture of air and oxygen, which is [illegible] and [illegible] supply only oxygen [illegible] air and [illegible] percentage of oxygen at [illegible]. These will now be passed around for your inspection. Please handle them with care.

The tubing before you is used in connecting the oxygen [illegible]. (Insert talk and demonstration.)

One of the most important parts of the oxygen equipment is the oxygen mask, based on two different principles, (1) the constant flow principle with rebreather [illegible] and (2) the demand principle. [illegible] these two principles have been combined so as to obtain the advantages of both without the disadvantages of either. (The various types will be demonstrated by the lecturer [illegible] depends on the aviator's understanding his equipment and the necessity of taking proper care of it.)

Army regulations regarding use of oxygen in flight are as follows: When

1. An altitude of 10,000 to 12,000 feet is contemplated for six hours or more.

2. An altitude of 12,000 to 15,000 feet is contemplated for two hours or more.

3. An altitude of 15,000 feet or higher is contemplated for any length of time.

In addition, all night flying is to be done with oxygen, since even small amounts of oxygen lack may [illegible] with night vision. Any individual with low altitude tolerance should not hesitate to use oxygen at lower altitudes than those specified above.

Before leaving oxygen I wish to correct some misconceptions concerning oxygen. Oxygen as used today has absolutely no deleterious effect on the teeth or the hair [illegible] even if used repeatedly for hours, [illegible]. Oxygen is used in the treatment of pneumonia, heart disease and many other medical conditions, and [illegible] oxygen is [illegible], and that high pressure oxygen, in contact with oil or grease will explode. There is no such thing as "medical oxygen". [illegible] are more often regulated [illegible] the valves [illegible] frequently changed. In aviation, however, for high altitude [illegible] oxygen must be used, otherwise the [illegible] oxygen [illegible] may freeze [illegible] valve. If this [illegible] the aviator will be suddenly deprived of his oxygen supply.

b. [illegible] of Physical Condition to Oxygen Requirement

There is a definite relation between one's physical condition and the harmful effects of [illegible] lack of oxygen [illegible] susceptible to the effects of oxygen lack, especially if [illegible]. Your [illegible] physical [illegible] [illegible]

the physical condition, the worse the reaction. A balance between sufficient sleep and proper exercise will tend to prevent fatigue. Fatigue is associated with inefficiency, weakness, weariness, and lack of perseverance. Fatigue is aggravated by anoxia.

Improper diet is also detrimental. Try to eat a well-balanced diet always. Don't overstuff yourselves at mealtime, and don't attempt to lose weight by dieting without first consulting your flight surgeon. Digestive disturbances, irritability, constipation, early fatigue, inefficiency, etc. may result from improper diet. The diet supplied you while you are cadets is well balanced.

Drugs are often taken indiscriminately by flying personnel - a dangerous practice. Always consult your flight surgeon before taking any kind of drug: sedatives such as seconal, phenobarbital, amytal, nembutal, etc. may result in tragedy, especially if one attempts to fly while still under the prolonged effects of these drugs. The nervous system and entire body are affected by sedatives.

Under no conditions should flying personnel take "on their own" any of the sulfonamid group of drugs. Among these drugs which are used by physicians to combat infections of various types are sulfapyridine, sulfanilamide, and sulfathiazole. Their effects on the blood, heart, nervous system, etc., are so pronounced that they are extremely dangerous for self-administration. The effects are so dangerous, that Army regulations permit Army physicians to prescribe these drugs only to hospitalized cases - those that can be observed at least daily and who can have blood counts daily if needed.

Even headache powders such as Bromo- Seltzer, "B-C", and other patented preparations may cause a severe agranulocytosis in the blood which seriously affects your susceptibility to anoxia, to say the least. In short, consult your flight surgeon before taking <u>any</u> drug!

Alcohol has often been used to pickle and preserve dead things, and many now "preserved things" were pickled just before dead! Avoid alcohol if you expect to get near any kind of machine - especially an airplane. With a little substitution the highway signs may well be used in flying: "If you fly, don't drink." Even reporting to the flying line with a slight trace of alcohol on the breath is a serious offense. We are all familiar with the dangers of alcohol, and it will perhaps suffice if you are reminded of the marked impairment in judgment resulting from alcohol. If you've imbibed a little too much the night before, report to your flight surgeon, and he will in peace time relieve you from flying that day. Think a hundred times before endangering your life, and the lives of others and expensive government property.

VI. <u>Barometric Pressure Changes and the Ear.</u>

As mentioned previously, ascent to high altitudes (decreasing barometric pressure) affects the ears, sinuses and intestines. We shall first consider the ear. If you will notice the chart of the ear's anatomy, you will see the external auditory canal, the ear drum or tympanic membrane, and the eustachian tube. (Instructor uses pointer on anatomical chart.) The external auditory canal is what the physician peeks into with an otoscope to get a good view of the ear drum (tympanic membrane). The tympanic membrane may be compared to a sheet of thin rubber in its ability to "pooch out" (bulge) and "pooch in" (retract), especially

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

if that sheet of rubber is thought of as covering one end of a tube. By blowing into the open end of the tube, the rubber sheet will bulge outward, and if we suck in on the open end, we create a negative pressure and cause the rubber sheet to retract; and the rubber sheet will burst. Similarly, the tympanic membrane will bulge out if the atmospheric pressure in the middle ear is greater than that in the external auditory canal and outside atmosphere; and if the pressure in the middle ear is less than that in the atmosphere, then there is a retraction of the tympanic membrane.

The principal action of the eustachian tube is to drain and ventilate or equilibrate the middle ear. We are primarily interested in its equilibrating or ventilating action. The eustachian tube is opened by its dilator muscles in the nasopharynx; opening, it equalizes any pressure differential existing between the middle ear and the atmosphere. The dilator muscles act to open the eustachian tube during swallowing, yawning and the other physiologic acts.

If we begin at sea level and ascend without ventilating the middle ear by opening the eustachian tube, there is pain with a bulging outwards of the ear drum with the degree of bulging dependent on the altitude attained. As we ascend, the pressure in the non-ventilated middle ear remains the same as it was at sea level, while the atmospheric pressure decreases. Hence the greater pressure in the middle ear pushes the tympanic membrane outward toward the lesser pressure of the atmosphere. If sufficient altitude is reached, the bulging may be great enough to burst the tympanic membrane. Similarly, if we assume the middle ear and atmospheric pressure have been equalized at high altitude and then begin to descend without ventilating the middle ear, we have a reversal of the process, i.e., the tympanic membrane is pushed inward. The pain and other symptoms are more prominent on descent than on ascent. If there is no middle ear ventilation during descent, then its pressure remains stationary with development of a relative negative pressure, while the atmospheric pressure progressively becomes greater and forces the tympanic membrane in toward the middle ear resulting in a retracted ear drum.

In this instance, there is a negative pressure within the middle ear while that of the atmosphere is a positive pressure. A negative pressure of 80 to 90 mm. of mercury or more makes it impossible for the eustachian muscles to overcome this negative pressure which holds the eustachian tube tightly collapsed. It then becomes necessary to decrease the middle ear pressure to about 70 mm. of mercury of negative pressure or less before the eustachian tube can again be voluntarily opened. This necessitates ascending again to an altitude where the middle ear and atmospheric pressure are more nearly equalized. "Aero-otitis media" or "aviation ear" is a term employed in referring to the results due to the lack of ventilation of the middle ear during changes of atmospheric pressure resulting in injury to the tympanic membrane. The two principal causes of improper middle ear ventilation are: first, a failure to open the eustachian tube voluntarily when necessary; second, inability to open it which is much more prevalent than is generally recognized. Frequent causes of inability to open the eustachian tube are: ignorance of the physiologic mechanisms, obstructions of the nose, sinusitis, tonsillitis, tumors or growths of the nose, mouth, etc. On the other hand, experience and training greatly increase one's ability to open the eustachian tube. Every flight surgeon has had innumerable experiences with the cadet who thought he should certainly not be grounded because he had a sore throat. The flight surgeon realizes only too well the dangers of a sore throat. The inflammation of the throat often involves the opening of the eustachian tube and causes a partial or complete closure of

[illegible]

[illegible]

[illegible]

[illegible]

the tube so that proper ventilation of the middle ear is not possible and woe betides the flier who flies with a sore throat and then after landing "blows his ears out" by closing the nose and mouth. Usually this forces germs from the infected throat into the eustachian tube and middle ear leading to serious complications.

Let us briefly consider the symptoms of aero-otitis media which may be brought on by ascent or descent with improper ventilation of the ears. One of the earliest symptoms is a feeling of fullness in the middle ear. In chronic cases due to repeated mild injury to the ears, there is a "full and stuffy" feeling in the ears and difficulty in "clearing" them. Varying degrees of loss of hearing may occur and be accompanied by head noises. In more severe cases the noises may be hissing, roaring, or crackling in character. Actual pain and dizziness may occur and become unbearable, with rupture of an ear drum. The subject feels "as though hit along the side of the head with a plank" and there is a sharp piercing pain on the affected side with marked dizziness and nausea. Collapse or shock may follow.

Again, the simplest maneuver to open the eustachian tube is to swallow. Yawning, singing, shouting, etc., may also accomplish it. The sucking of candied mints while flying causes frequent swallowing and is probably better than chewing gum, as the latter soon loses its flavor. The average person swallows involuntarily about once very 60-75 seconds so that rates of climb of 500 feet per minute or more result in progressively greater degrees of discomfort if no effort is made to ventilate the middle ear. Sleeping and unconscious individuals present a serious problem. Commerical air lines have an allowable rate of ascent and descent of 200 to 300 feet per minute. However, military flying requires more rapid rates of ascent and descent with, of course, greater care regarding the ears.

VII. Barometric Pressure Changes and the Sinuses.

The nasal accessory sinuses are also affected by barometric changes. These are located in the hollowed out spaces of the face bones. Two of these sinuses are located here (demonstrate) in the cheek bone, two are located here in the forehead, and two of them are located in the bones just back of the root of the nose. Ordinarily air passes in and out of those sinuses through small openings in the nose. During ascent and descent to and from high altitudes, the air in these sinuses changes pressure with the atmospheric pressure, as does the air in the middle ears, and similarly, should there be an obstruction to the sinuses, the air cannot escape readily and ill effects are produced. For instance, in ascent the expanded air in the sinuses cannot escape, and by building up pressure within the sinuses it causes pain. The reverse of this is true during descent when a vacuum is created in the sinuses and air from the atmosphere cannot enter the sinuses. Pain is produced here also and may be accompanied by headache, eyeache, dizziness, and nausea. Pilots with sinus infection, obstructed sinus opening, or head colds, should not fly until the condition has been corrected To do so may aggravate the condition and perhaps cause serious complications. A benzedrine inhaler sniffed just before flying may help at times but warning is given that the inhaler should be used not more often than once every hour and should only be used after consulting your flight surgeon.

VIII. Barometric Pressure Changes and Intestinal Gases.

Expansion of abdominal gases may cause marked discomfort in high altitude flying. Gases expand with decrease in atmospheric pressure. For example, a toy balloon when taken from sea level to 35,000 feet will increase its volume more than five times. Similarly, the intestinal gases will do likewise, often leading to marked abdominal distension and discomfort. When abdominal cramps are marked, difficulty in breathing and interference with the heart's action may result. Anyone contemplating a high altitude flight should avoid gas forming foods and drinks such as beans, cabbage, peas, beer and carbonated drinks. Avoid constipation. Once distension and discomfort are experienced, relief may be obtained by either descending to lower altitudes or by massaging the abdomen with the hand followed by belching and the passage of flatus.

IX. Hyperventilation.

There is one more important thing to consider, and that is hyperventilation, "Hyper" meaning very much or too much, and "ventilation," meaning just that. In hyperventilation there is more breathing, or ventilation, than is necessary for the requirements of the body at that time. The symptoms of hyperventilation may be serious, and are: dizziness, a rapid pulse, marked perspiration, claminess of the skin, visual disturbances, errors in judgment, muscular spasms and unconsciousness. Hyperventilation usually occurs insidiously, coming on without the victim being aware of it unless he is familiar with the signs and symptoms. Anxiety as during combat, fear, panic or hysteria often cause hyperventilation, thus adding to the seriousness of the situation. The treatment, fortunately, is quite simple, just hold the breath for about one minute in order to build up the carbon dioxide content of the blood which was diminished by hyperventilating. We shall now have six members of the class hyperventilate under my direction for 2½ minutes and at the conclusion I shall have them describe to the class the symptoms they have experienced.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

SUGGESTIVE OUTLINE FOR LOW PRESSURE CHAMBER
"RUN" FOR BEGINNING AVIATION CADETS.

Operating personnel: Two trained medical officers, one trained chamber operator, one trained mechanic.
Time required: Approximately one hour.

1. Inquire as to whether any students have colds, ear or sinus symptoms. Leave these students out of chamber ascent.
2. Explain that high altitudes will be simulated by exhaustion of air pressure in chamber.
3. Demonstrate oxygen supply system.
4. Explain that tests for mental and physical changes will be made in the chamber.
5. Close chamber door after all students are seated. Take slightly filled toy balloon along to demonstrate expansion of gases.
6. Medical officer and alternate one-half of students put on oxygen masks. Medical officer has microphone connected to public speaker system and also to operator outside of chamber by earphones.
7. Ascent made to 5000 feet. Altitude announced. Notify students that a descent 1500 feet in one minute is to be made and students are to swallow and care for ears and sinuses.
8. Descend to 3000 feet. Then descend to ground level and remove from chamber those students with marked ear or sinus symptoms, and send them to E.N.T. department for examination.
9. Ascend to 5000 feet. Give written test. Be certain that alternate students only are using oxygen with mask.
10. Ascend to 18,000 feet at a rate of 4,000 to 5,000 feet per minute. Carefully note reactions of students while ascending for fear, uneasiness, calmness, hyperventilation, etc. Give proper assurance and instruction.
11. At 18,000 feet give written test to students, after ten minutes.
12. Have students not taking oxygen compare with the students next to them who are using oxygen the color of their fingernails, earlobes, and skin. Have students write down any sensations noted, especially as to clearness of vision, clearness of mind, rapid pulse rate, respiratory changes, irritability, etc.
13. Have all students put on masks with oxygen. Check each mask and oxygen supply. After 5 minutes have students again write down sensations. Call their attention to changes now noted with the use of oxygen in those who were not using oxygen previously.
14. Announce ascent to 30,000 feet to be made. Assure students of safety. Answer questions. Ask students to record sensations while ascending, and to note lessened effect on ears and sinuses than when ascending from ground to 12,000 feet. Have them note balloon expansion.
15. Signal ascent to 30,000 feet.
16. Remain at 30,000 feet 10 to 15 minutes. Have students record sensations. Give written test. Comment on comfort as compared with 18,000 feet. Comment on intestinal gas expansion. Exhibit balloon.
17. If any student has marked symptoms from intestinal gases, descend to 25,000 feet for 3 to 5 minutes, then return to 30,000 feet. Review symptoms of anoxia.
18. Announce descent to be made at 3000 feet per minute to 10,000 feet, then at 2000 feet to ground level. Warn about ears and sinuses. Level off if marked complaints given.
19. Signal descent.
20. Remove oxygen masks at 10,000 feet altitude.
21. Answer student questions.
22. Record findings and impression of each student.

LECTURE AND DEMONSTRATION OUTLINE FOR
INSTRUCTORS OF AIR FORCE AND MEDICAL OFFICERS

Concerning

FLIGHT PROPHYLAXIS

Equipment: 1. Proper charts showing barometric changes with altitude, the anatomy of the ear, physiology of a blackout, etc.
2. Various types of oxygen equipment, i.e., masks, tanks, etc.
3. Blackboard.
4. Motion pictures.

Time: Approximately two hours.

I. Introduction.
A. Relation of aviation medicine to flying.
B. Responsibilities of flying officers.
1. To selves.
2. To crew.
a. Informed constantly concerning
(1) Course.
(2) Altitude.
(3) Maneuvers, etc.
b. Trained to care properly for selves.
3. To passengers, i.e., wounded.

II. The Atmosphere.
A. Definition.
B. Atmospheric pressure.
1. Definition.
2. High altitude; thin air; decreased atmospheric pressure.
3. Molecular action.
4. Torricelli's experiment.
5. Measuring of atmospheric pressure.
C. Composition of atmosphere.
1. Volume.
a. Nitrogen - 78%; roughly 4/5.
b. Oxygen - 21%; roughly 1/5.
c. Rare gases - 1%.
2. Partial pressure.
a. Definition.
b. Variability with altitude.
c. Effect on available amount of oxygen.
(1) Supply to lungs.
(2) Supply to blood and tissues.
d. Relation to manifold pressure.
D. Vertical section of the atmosphere.
1. Division by layers.
a. Troposphere.
(1) Definition.
(2) Characteristics.
(a) Contains 3/4 of atmosphere by weight.
(b) Contains hydrometeors.
1. Clouds.
2. Rain.
3. Snow.

b. Stratosphere.
(1) Definition.
(2) Characteristics.
(a) Relatively constant temperature, 55° C.
(b) Hydrometeors absent.
c. Tropopause.
(1) Definition.
d. The term "substratosphere" is a convenient term to indicate flights between 35,000 and 42,000 feet.
2. Flight surgeon's division.
a. Upper limit of unimpaired performance; 10-11,000 feet.
(1) Individual variability.
(2) "Physiological zone of the atmosphere."
b. Critical limit; 20,000 feet.
(1) Unconsciousness and death; 23,000 to 28,000 feet.

III. Tactical Considerations in Altitudes.
A. World War I.
1. Combat altitude often 15,000 to 18,000 feet.
B. World War II.
1. Combat altitude often 20,000 to 30,000 feet; becoming 30,000 to 40,000 feet.
C. Advantages of high altitudes.
1. Interception less probable for bombers.
2. Greater operating freedom.
3. Detection probability less.
4. Progressively less danger from anti-aircraft.
D. Mechanical problems.
1. Supercharging; crank case; magnetos; ignition systems, etc.
2. Intercooling.
3. Lubrication.
4. Pressure cabins and suits.
5. Heating.

IV. Effects of Lack of Oxygen.
A. Organs affected.
1. Brain and nervous system - very susceptible.
2. Heart.
3. Muscles.
4. Rest of body.
B. Amount and extent of body changes.
1. Dependent on following factors: (assuming a healthy man).
a. Altitude attained.
b. Duration of exposure to lack of oxygen.
c. Frequency of flight.
2. Individual factors varying reactions to lack of oxygen.
a. Natural ability.
b. Physical activity.
c. General physical condition.
C. Subjective symptoms.
1. 10,000 - 12,000 feet up
a. Unawareness of the progressive effects of decreasing oxygen pressure (increased altitude).
b. Pulse rate increase; compensatory.
c. Surprisingly little increase in depth or rate of respiration.

d. Euphoria.
e. Poor judgment with poor mental and physical response.
f. Dizziness.
g. Unconsciousness.
h. Headache and fatigue on recovery.
i. Accessory symptoms, i.e., ear pain, sinus pain, etc. discussed later.

V. <u>Use of Oxygen During Flight</u>.
  A. Advantages.
    1. Prevention of symptoms of oxygen lack - prophylactic.
  B. Precautions.
    1. Complete equipment check before flight.
    2. Avoid flames.
    3. Avoid oils or grease on any metal oxygen connections.
    4. Seal tank threads with lead oxide and glycerine.
    5. Must be 99% pure.
    6. Store cylinders in cool, dry place.
  C. Equipment.
    1. Oxygen tanks.
      a. High pressure.
        (1) Advantages.
        (2) Disadvantages.
      b. Low pressure.
        (1) Advantages.
        (2) Disadvantages.
    2. Regulators.
      a. Manual type.
      b. Demand type.
    3. Tubing connections.
    4. Masks.
      a. Types.
      b. Precautions.
        (1) Fit.
        (2) Understanding principle of mask.
    5. When to use masks in flight.
      a. 10-12,000 feet; 6 hours or more contemplated.
      b. 12-15,000 feet; 2 hours or more contemplated.
      c. 15,000 feet or more always.
      d. At lower altitudes if individual low altitude tolerance present.
  D. Emergency parachute jumps from high altitudes, use of oxygen.
    1. 35,000 feet.
      a. In region where human life non-existent without oxygen.
      b. At least 8-15 minutes from safety in open parachute.
      c. Unconsciousness in 35 seconds.
      d. Danger of delayed open 'chute jump with no oxygen.
      e. Danger of delayed jump with no oxygen.
      f. Emergency midget tank.
        (1) 10-15 minute supply.
        (2) Carried in pants leg (reinforced).
        (3) Tubing under clothes.
        (4) Special mask; mouth bite.
        (5) Adjust before attempting to leave seat; first maneuver.

E. Misconceptions concerning oxygen.
   1. Effect on teeth and fillings.
   2. Effect on lungs.
   3. Inflammability. One drop of Oil makes high pressure oxygen explosive.

VI. <u>Relation of Physical Condition to Oxygen Requirements.</u>
   A. Lack of sleep and exercise.
   B. Improper diet.
   C. Drugs and alcohol.
      1. Sedatives.
      2. Headache powders.
      3. Sulphonamids.
      4. Excessive tobacco.
      5. Alcohol.

VII. <u>Aero-emphysema or Aeroembolism.</u>
   A. Definition.
   B. Mechanism of:
      1. Atmospheric pressure change.
      2. Role of nitrogen.
      3. "Soda pop" illustrations.
      4. Physiological changes - similarity to diver's bends.
   C. Symptoms.
      1. Factors in production.
         a. Rate of ascent.
         b. Altitude attained.
         c. Time remaining at altitude.
         d. Individual susceptibility.
      2. Symptoms experienced (subjective).
         a. Eyelid scratching and smarting.
         b. Skin crawling.
         c. Joint and extremity pain.
         d. Dizziness.
         e. Deafness.
         f. Paralysis.
      3. Prophylactic measures: preliminary decompression (denitrogenization) with special equipment.
         a. 100% O_2; $2\frac{1}{2}$ - 3 m.p.h. exercise rate.
         b. Treadmill, bicycle, standing walk, etc.

VIII. <u>Effects of Heat and Cold.</u>
   A. Effect of cold on body - mechanism for maintaining body temperature.
      1. Normal body temperature.
      2. Metabolic rate.
         a. Definition.
         b. Factors affecting metabolic rate.
   B. Atmosphere.
   C. Effects of freezing on the body.
      1. Often no subjective symptoms.
      2. Early stages.
      3. Later stages.
   D. Protection against cold.
      1. Cold cream, vaseline, bland ointments on exposed parts.
      2. Clothing.
         a. Not too bulky.

b. Two thin garments better than one thick garment.
c. Not too tight; snug at wrists, collar, ankles.
d. Electrically heated.
(1) Disadvantages.
(a) Heat source may fail.
(b) Not practical if ship abandoned.
(c) Requires much electrical energy.
3. Heated cabins.
a. Heat collection around exhaust to cabin.
(1) Carbon monoxide leakage.
b. Steam circulation.
(1) Satisfactory.

IX. Effects of Speed and Centrifugal Force.
A. Speed.
1. Straight-away flying.
a. Only danger in exposing parts of body to terrific air pressure.
B. Centrifugal force and speed.
1. In banks and turns.
a. Blackout.
(1) Definition.
(2) Physiology.
(a) Direction of blood flow.
(b) Effect on visual fields.
(c) Maximum blackout point.
1/ Role of "pull out" angle in
2/ Role of speed in
(d) Importance in combat.
1/ Temporary loss of plane control.
2/ Enemy in darkened area of visual field.
3/ Probable effect of repeated blackouts.
(e) Prophylaxis.
1/ Abdominal belt.
2/ Crouch position.
3/ Prone position.
4/ Tightening of collar.
5/ Shouting.
(f) Blood pressure in blackout.
1/ Susceptibility of hypertensive and hypotensive individuals.
b. Redouts.
(1) Definition.
(2) Physiology of:
(a) Direction of blood flow.
(b) Effect on visual field.
(c) Maximum redout point.
1. Radius of circle.
2. Speed.
(d) Effect of repeated redouts.
1. Minute hemorrhages.
2. Apoplexy.
(3) Blood pressure in:
(a) Susceptibility of hypertensive and hypotensive individuals.

X. <u>Barometric Pressure Changes and the Ear.</u>
  A. Ear anatomy.
    1. Tympanic membrane (ear drum))
    2. Eustachian tube) Emphasized.
  B. Ascent.
    1. Effect on tympanic membrane.
      a. Eustachian os opened; mechanism.
      b. Eustachian os closed; mechanism and symptoms.
  C. Descent.
    1. Effect on tympanic membrane.
      a. Eustachian os opened; mechanism.
      b. Eustachian os closed; mechanism and symptoms.
        (1) Negative pressure over 80 mm. Hg.
        (2) Very high negative pressure; rupture.
  D. Aero-otitis media ("ear block", "aviation ear").
    1. Definition.
    2. Causes of improper middle ear ventilation.
      a. Failure to open eustachian tube.
        (1) Ignorance.)
        (2) Carelessness) Inexperience.
      b. Anatomical causes.
        (1) Upper respiratory infections.
        (2) Nasal obstructions.
        (3) Sinusitis.
        (4) Tonsillitis.
        (5) Nose and mouth tumors.
      c. Inability to open eustachian tube.
        (1) Sedatives.
        (2) Anesthetics.
        (3) Unconsciousness.
        (4) Shock.
    3. Symptoms.
      a. Fullness in middle ear; "stuffy".
      b. Varying degrees of hearing less.
      c. Head noises; hissing, roaring, etc.
      d. Pain.
      e. Vertigo.
      f. Rupture; collapse; or shock.
    4. Prophylaxis.
      a. Education.
      b. Correction of anatomical deformities, etc.
    5. Swallowing.
      a. Average rate - once per 60-75 seconds.
      b. 500 feet or more ascent per minute may cause discomfort.
      c. Commercial rates 200-300 feet per minute.
      d. Rapid descent and ascent in military work.
    6. Other dangers.
      a. Sore throat; "blowing ears out"; middle ear infection.

XI. <u>Barometric Pressure Changes and the Sinuses.</u>
  A. Brief Anatomy.
  B. Ascent.
    1. Sinuses open.
    2. Sinuses obstructed.
      a. Symptoms.

C. Descent.
   1. Sinuses open.
   2. Sinuses obstructed.
      a. Symptoms.
D. Treatment.
   1. Benzedrine inhaler (caution).
   2. Correction of cause of obstruction.

XII. Barometric Pressure Changes and Intestinal Gases.
A. Physiology of expansion of gases.
   1. Toy balloon illustration.
   2. Volume increased 4 times at 35,000 feet.
B. Symptoms.
   1. Distention, discomfort, cramps.
   2. Dyspnea, cardiac embarrassment.
C. Treatment.
   1. Abdominal massage with belching and passing of flatus.
   2. Powdered charcoal tablets orally.
D. Prophylactic diet.
   1. Avoid beans, cabbage, peas, beer and carbonated drinks.
   2. Avoid constipation.

XIII. Hyperventilation.
A. Definition.
B. Physiology.
   1. Decreased blood CO_2.
   2. Alkalemia.
C. Symptoms.
   1. Vertigo.
   2. Rapid pulse.
   3. Perspiration.
   4. Coldness; clamminess.
   5. Visual disturbance.
   6. Judgment errors.
   7. Carpo-pedal spasm.
D. When found.
   1. Anxiety, i.e., combat.
   2. Fear.
   3. Panic.
E. Treatment.
   1. Holding breath about one minute
F. Demonstration.

LECTURE FOR AIR FORCE AND MEDICAL OFFICERS

Material Required: 1. Proper charts showing barometric changes with altitude, the anatomy of the ear, physiology of a blackout, etc.
2. Blackboard.
3. Various types of oxygen equipment.
4. Moving pictures.

Time Required: Approximately two hours.

I. Introduction.

A. Relation of aviation medicine to flying.

Without aviation medicine and flight surgeons aviation would probably not have progressed to its present advanced stage. Probably no other occupation requires as great a degree of coordination between mind and body as does aviation. In addition to carrying on their duties of selecting favorable men for pilots and maintaining the health and value of the older pilots, the flight surgeons and civilian physicians have done commendable work in attempting to make the human machine as fit as the mechanical machine by continuous experimentation and research.

The Collier Trophy which, as you know, is awarded to those individuals or organizations who have contributed most to the progress of aviation, was given in 1940 to three physicians. Two of these were civilians and one was an Army flight surgeon.

B. Responsibilities of flying officers.

Perhaps the greatest reason for this lecture is to make you fully realize some of the dangers of flying and to inform you as to the protective measures you should use to combat these dangers - in short, flight "prophylaxis." The pilot and crew of combat planes are highly trained individuals. It is your responsibility to take proper care of all the men who are dependent upon you, not only the crew but also in many instances the sick and wounded passengers. You must understand the dangers involved in high altitude flying and all the methods used for the safety and efficiency of the human machine in the air. You must understand not only the mechanical phases of flying, but also be able to thoroughly instruct and supervise your crew and to transport with safety any casualties or wounded passengers assigned to you for evacuation. Problems that may confront you later may be as follows: How high should I fly with a passenger ill with pneumonia? How rapidly may I descend with a passenger having severe injuries with shock? What steps must I and my rew take in order to avoid a lack of oxygen at high altitudes?

The pilot should at all times, if possible, keep his crew members informed of any anticipated changes in altitude, course, or maneuvers so that the crew members may properly care for themselves during these changes. The pilot should assure himself that the crew members are familiar with the procedure necessary to take care of themselves in preventing ear and sinus symptoms, blackouts, aeroembolism, etc. If necessary, he should instruct them concerning these necessary procedures.

II. The Atmosphere.

A. Definition.

The atmosphere may be defined as the layer of air surrounding the earth. This layer of air is approximately sixty-two miles thick (327,360 feet).

B. Atmospheric Pressure.

This layer of air (the atmosphere) has mass and weight, and its weight or pressure exerted on the earth's surface at sea level is known as the "atmospheric pressure" at sea level. The air layers nearest the earth's surface are pressed on by the air layers above so that the air at lower altitudes is more dense and under greater pressure than those at higher altitudes. Thus, the higher the altitude, the "thinner" the air and the lower the barometric pressure. As an example, if we have a pile of duck feathers uniformly mixed with chicken feathers, the feathers at the bottom of the pile are more compressed than those at the top, and a cubic foot of feather mixture from the base of the pile will contain more feathers than a cubic foot taken from the top. However, the percentage of each kind of feathers will be the same. The barometric (or atmospheric) pressure at sea level under standard conditions is 760 mm. Hg - that is, it is equal to the pressure a column of mercury 760 mm. high would exert. This figure (760 mm. Hg) may also be expressed as 29.9 inches of mercury.

Toricelli's experiment, as your probably remember, illustrates the measurement of atmospheric pressure and the fact that this pressure is equal to the weight of the column of air which lies above the surface involved. Toricelli used a glass tube more than 30 inches long, closed at one end, and filled with mercury. This he inverted over an open vessel containing mercury. The mercury in the tube descended, leaving a vacuum above it. The vertical height of the column of mercury measured the atmospheric pressure; 760 mm. or 29.9 inches at sea level.

C. Composition of atmosphere.

1. Volume.

By volume the atmosphere is composed of 78 per cent nitrogen, 21 per cent oxygen (more accurately, 20.93%), a small amount of carbon dioxide (0.03%) and traces of rare gases (about 1%); that is roughly 4/5 nitrogen and 1/5 oxygen.

2. Partial pressure.

According to Dalton's law, the partial pressure of a specific gas in a mixture of gases is the pressure exerted by the specific gas only - that is, the pressure that the specific gas would exert if it alone occupied the space of the whole gaseous mixture. Since oxygen composes 21% of the atmospheric air, then at sea level the partial pressure of oxygen is 21% of 760 mm., or 159 mm. Hg. Partial pressures are important, especially that of oxygen for it is the partial pressure that forces oxygen through the walls lining the air sacs of the lungs into the blood and from there it is transported to the tissues. Since the barometric pressure decreases with increase in altitude, the partial pressure of oxygen also decreases so that at higher altitudes less oxygen is driven into the blood from the lungs.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

D. Vertical section of the atmosphere.

1. Division by layers.

We divide the atmosphere into layers. These are: the troposphere, stratospheré, and the tropopause. They are shown on this chart. (Demonstrate.)

The troposphere extends from sea level to about 33,000 to 35,000 feet altitude. It contains three-fourths of the atmosphere by weight and various hydrometeors as clouds, rain and snow.

The stratosphere extends about 37,500 feet to hundreds of miles of altitude. Here the temperatures are much more constant than in the troposphere being from 62 to 71 degrees below zero (Fahrenheit). Hydrometeors are absent here.

The tropopause varies from about 33,000 to 40,000 feet and is the area between the upper limit of the troposphere and the lower limit of the stratosphere.

2. Flight Surgeon's division.

From the flight surgeon's point of view it is probably only necessary to divide the atmosphere in a rough manner; that is, first, the upper limit of unimpaired performance, which is at an altitude of 10,000 to 11,000 feet, and, second, the critical limit, which is at 18,000 to 20,000 feet. Ten to eleven thousand feet is set as a limit because most individuals can fly at those altitudes for an hour or more without severe effect on the body. However, some individuals have a less resistance even to a small lack of oxygen. They may experience symptoms of lack of oxygen after several hours of flying at only 8,000 feet over a period of days. At the critical limit of 18,000 to 20,000 feet danger of unconsciousness and even death is present. On any flight for any length of time at 15,000 feet or more oxygen must be used.

III. Tactical Considerations in Altitudes.

Let us briefly consider military tactics and altitudes. In World War I combat often took place at altitudes of 15,000 to 18,000 feet. In World War II combat altitudes are often from 20,000 to 30,000 feet and are rapidly progressing toward 40,000 feet. In the future, perhaps it will be over 40,000 feet with the use of pressure suits or pressurized cabins.

The advantages of high altitude are:

1. Interception is less probable for bombers.
2. There is greater operating freedom.
3. There is less probability of detection.
4. There is progressively less danger from anti-aircraft.

High altitude flying has, on the other hand, created many mechanical problems such as supercharging, intercooling, lubrication, pressure cabins and suits, and heating. Progress has been made in meeting these problems.

IV. Effects of Lack of Oxygen.

Without oxygen, an averate individual can carry on efficiently for only the following lengths of time at the following altitudes:

35,000 feet - about 35 seconds
25,000 feet - about 5 minutes
20,000 feet - about 10 to 15 minutes
18,000 feet - about 45 to 75 minutes
15,000 feet - about 5 to 6 hours
10,000 feet - all day, but symptoms of chronic oxygen lack will be present if repeated daily.

A very important figure to remember is 35 seconds at 35,000 feet before the subject becomes completely unconscious; this is equivalent to about seven breaths.

Increase in altitude (decrease in atmospheric pressure) will result in the following effects on the human body.

1. Altitude sickness due to lack of oxygen (anoxia).
2. The effects due to decreased pressure such as expansion of gases in the abdomen and in the middle ear, and also aero-emphysema and aeroembolism.
3. The effects of cold.
4. Airsickness, which is due to the motion of the ship and is similar to seasickness.

In considering the full effects of lack of oxygen special stress is to be put on some of the organs affected. The brain and nervous system are very susceptible to even small amounts of oxygen lack. The heart, muscles and other parts of the body are also affected. The amount and extent of body changes are dependent on the following factors, assuming that we have a healthy man:

1. Altitude attained, since the higher the altitude the less the availability of oxygen to the body.
2. The duration of the lack of oxygen, since the longer the duration the more changes there are.
3. The frequency of flight. Repeated trips on successive days to altitudes producing only very slight lack of oxygen will, if frequently repeated (as daily for a month), cause definite symptoms of impaired mental and physical functions.

There are several individual factors which affect responses to a lack of oxygen. These are natural ability, physical activity and general physical condition. Some individuals have a natural ability to show little change to moderate amounts of oxygen lack - that is, they have a high resistance to lack of oxygen; their symptom threshold is high. This was important in the previous war when ability to go to 20,000 feet made you superior in fighting an enemy that could only go to 18,000 feet. Today this difference is insignificant because with proper oxygen equipment you can go to 33,000 feet and be normal and can reach 42,000 feet as safely as you could formerly reach 20,000 feet, as far as oxygen is concerned. Increased physical activity stimulates body metabolism and oxidation so that more oxygen is needed by the body, and if the

additional supply of oxygen is not received, then symptoms of oxygen lack set in earlier and are more severe than if the body were at rest. An individual in good general physical condition almost invariably reacts less to the same amount of oxygen lack than does one in poor physical condition, assuming everything else to be equal.

There is surprisingly little awareness of the progressive effects of decreasing oxygen pressure. There is usually a compensatory increase in the pulse rate, but only a little increase in depth or rate of respiration. Euphoria (a false sense of well-being) and poor judgment with poor mental and physical response are usually followed by dizziness and unconsciousness with possible disastrous results. Should consciousness be regained, headache and marked fatigue will be noted. Accessory symptoms, as earache, will be discussed later. The symptoms of anoxia are very similar to those of alcoholic intoxication.

V. Use of Oxygen During Flight.

A. Advantages.

The one big advantage in using additional oxygen is that by so doing one prevents an oxygen lack, a simple but important fact. Benefits of oxygen administration may be summed up in one word - "prophylaxis."

B. Precautions.

Before attempting to use oxygen we should become familiar with a few precautions we should use. First, and perhaps of most importance, is a habitual complete check of oxygen equipment before flights. Either you or someone you are certain is a responsible individual should make the check. Avoid flames! Oxygen makes things more inflammable. Avoid using oils or greases on any metal oxygen connections. Oils and high pressure oxygen can result in a tremendous explosion! Warn your mechanics. Cylinders should be stored in a cool, dry place and not handled too roughly. Tank threads should be sealed with a lead oxide and glycerine preparation instead of greases.

C. Equipment.

1. Oxygen tanks.
You see here some of the various oxygen tanks used by the Army. (Demonstration and short discussion of the characteristics of the various tanks, i.e., low pressure, high pressure, etc., and discuss tank "poundage," refilling, and the necessity for using dry oxygen)

2. Regulators.
Here we have some of the various types of oxygen regulators in use. These (demonstrate) are the hand controlled type and should be set at the altitude at which one is flying if sitting quietly, and 5000 to 8000 feet higher if exercising. Some flow meters are correctly marked on one side for "resting" flow and on the other side for use if the aviator is "active"; that is, using his muscles by working. These (demonstrate) are the demand types which supply oxygen according to the demands of the body. They are automatic and will supply more oxygen at higher levels or while the individual is active instead of resting. There are two types of demand regulators. One type mixes the necessary amounts of air and oxygen, and is best suited to altitudes under 30,000 feet. The other type supplies only oxygen with no added air, and is therefore wasteful of oxygen at altitudes below 30,000 feet. These will now be passed around for your inspection. Please handle them with care.

[illegible] supply of oxygen is not received. [illegible] symptoms [illegible] oxygen lack, [illegible] [illegible] [illegible] [illegible] [illegible] in [illegible] [illegible] [illegible] [illegible] [illegible] results [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible].

[illegible] is [illegible] [illegible] [illegible] [illegible] [illegible] oxygen [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] a little increase in [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] with poor control, [illegible] [illegible] [illegible] [illegible] [illegible] with positive [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] will be [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] intoxication.

4. [illegible]:

1. [illegible]

[illegible] [illegible] [illegible] [illegible] additional oxygen [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] of oxygen. [illegible] may [illegible] [illegible] [illegible] [illegible] [illegible]."

2. [illegible].

[illegible] [illegible] [illegible] oxygen we should become familiar with a few [illegible] [illegible]. [illegible], [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] should [illegible] [illegible] [illegible]. Avoid [illegible] [illegible] [illegible] [illegible] [illegible] avoid [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] high pressure oxygen can result in [illegible] [illegible] [illegible] [illegible]. Cylinders should be stored in a cool, dry place [illegible] [illegible] [illegible]. [illegible] [illegible] should be sealed with [illegible] [illegible] [illegible] [illegible] instead of grease.

3. [illegible].

1. [illegible].

[illegible] [illegible] [illegible] of the [illegible] oxygen [illegible] used by the [illegible]. [illegible] [illegible] [illegible] [illegible] of the [illegible] [illegible] of the various [illegible], [illegible] [illegible] [illegible], and [illegible] [illegible] [illegible] [illegible], and the necessity for using [illegible].

2. [illegible].

[illegible] [illegible] [illegible] [illegible] of the [illegible] types of oxygen regulators in use. [illegible] [illegible] [illegible] [illegible] [illegible] and should [illegible] at the altitude [illegible] the other [illegible] [illegible] [illegible] [illegible] [illegible]; that is, [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] oxygen [illegible] [illegible] [illegible] [illegible]. They are automatic and will supply [illegible].

3. Tubing connections.
The tubing before you is used in connecting the oxygen apparatus. (Short talk and demonstration.)

4. Masks
One of the most important parts of our oxygen equipment is the oxygen mask. Here are some of the various types of masks in use. (Demonstrate.) This is the latest type issue. An excellent mask is the type A-8-A here shown. (Demonstrate.) It is of utmost importance that you use a proper fitting mask, and you should fully understand the principle or mechanism of operation of the mask you use.

(The latest masks and accessory equipment should be demonstrated very carefully and especial attention payed to the respective merits and demerits of the "constant flow system," the "demand system" and finally the "combined constant flow and demand systems" which has all the advantages of both systems with practically none of the disadvantages.)

5. When to use masks in flight.
Army regulations regarding use of oxygen in flight are as follows:
Oxygen is to be used in flights when
1. An altitude of 10,000 to 12,000 feet is contemplated for six hours or more.
2. An altitude of 12,000 to 15,000 fe et is contemplated for two hours or more.
3. An altitude of 15,000 feet or higher is contemplated for any length of time.

In addition, all night flying is to be done with oxygen, since even small amounts of oxygen lack may interfere with night vision. Any individual with low altitude tolerance should not hesitate to use oxygen at lower altitudes than those specified above.

D. Emergency parachute jumps from high altitudes.

What would you do if an emergency arose at 35,000 feet and a "bail out" was necessary? There you are in a region where unconsciousness sets in after 35 to 45 seconds without an extra oxygen supply; you are a number of minutes from a safe altitude at which the pressure of oxygen in the atmosphere would be sufficient to maintain consciousness. The aviator does not have time to get out of his plane unless the first thing he does after his oxygen supply has been shot away or damaged is to shift to the emergency midget oxygen tank. This is a small tank carrying fifteen minute's oxygen supply (demonstrate).

E. Misconceptions concerning oxygen.

Before leaving the subject of oxygen I wish to correct some misconceptions concerning oxygen. Oxygen as used today has absolutely no deleterious effect on the teeth or fillings and none on the lungs even if used repeatedly for hours. As a matter of fact, oxygen is used in the treatment of pneumonia, heart disease, and many other medical conditions. And let's not forget that high pressure oxygen in contact with oils or grease will explode. There is no such thing as "medical oxygen" since this is the same as what we use except for the tank label and valve connections. In aviation for high altitude flying relatively unheated dry oxygen must be used. Any water in it would freeze on the needle point of the reducing valve. Th is would cut off the oxygen flow to the aviator.

—

4. [illegible]
[illegible]

[illegible]

5. What is the means of flight.
[illegible] use of oxygen in flight [illegible] as follows:

1. an altitude of 10,000 to 12,000 feet is recommended for [illegible]
2. an altitude of 12,000 to 15,000 ft [illegible]
3. an altitude of 15,000 feet or higher is recommended [illegible]

[illegible]

6. [illegible]

[illegible]

7. [illegible]

[illegible]

VI. Relation of Physical Condition to Oxygen Requirements.

A. Lack of sleep and exercise.

There is a definite relation between one's physical condition and the harmful effect of oxygen lack; the ceiling is lowered if one's physical condition is poor. Lack of sleep makes us more susceptible to the effects of oxygen lack, especially if continued over a period of weeks or months. Your grammer school teacher's advice about getting eight or ten hours sleep nightly still holds good. As stated already, one's general physical condition is one of the factors determining reaction to a lack of oxygen. The worse the physical condition, the worse the reaction; hence, be certain you receive your rightful share of exercise and recreation. A balance between sufficient sleep and proper exercise will tend to prevent fatigue. Fatigue is aggravated by anoxia.

B. Improper diet.

Improper diet is also detrimental. Try to eat a well-balanced diet. Don't overstuff yourselves at mealtime, and don't attempt to lose weight by dieting without first consulting your flight surgeon. Digestive disturbances, irritability, constiptation, early fatigue, inefficiency, etc., may result from improper diet. The diet supplied you while you were cadets was well balanced.

C. Drugs and alcohol.

Drugs are often taken indiscriminately by flying personnel - a dangerous practice. Always consult your flight surgeon before taking any kind of drug! Taking sedatives such as seconal, phenobarbital, amytal, nembutal, etc.,may lead to tragedy, especially if one attempts to fly while still under the prolonged effects of these drugs. The nervous system and entire body are affected by sedatives.

Under no condition should flying personnel take any of the sulfonamid group of drugs which are used by physicians to control infections of various types. Among these drugs are sulfaphyridine, sulfanilamide, and sulfathiazole. Their effects on the blood, heart, nervous system, etc. are so pronounced that they are extremely dangerous for self-administration. The effects are so dangerous that Army regulations permit Army physicians to prescribe these drugs only to hospitalized patients, those who can be observed throughout the day and who can have blood counts daily if needed.

Even headache powders such as bromo-seltzer, "B-C" and other patent preparations may cause agranulocytosis in the blood which would seriously affect your susceptibility to anoxia, to say the least. In short, consult your flight surgeon before taking any drug!

Alcohol has often been used to pickle and preserve dead things and many now "preserved things" were pickled just before death! Avoid alcohol if you expect to get near any kind of a machine - especially an airplane. With a little substitution the highway signs may well be used in flying: "If you drink, don't fly. If you fly, don't drink." Even reporting to the flying line with a slight trace of alcohol on the breath is a serious offense. We are all familiar with the dangers of alcohol, and it will perhaps suffice if

you are reminded of the marked impairment in judgment resulting from alcohol. If you've imbibed a little too much the night before, report to your flight surgeon and he will relieve you from flying for that day. Think a hundred times before endangering your life, the lives of others, and expensive government property.

VIII. Aero-emphysema or Aeroembolism.

A. Definition.

Aero-emphysema is a term used to designate the presence of air bubbles of very small, usually microscopic, size in the tissue cells or in the intercellular fluids of the body.

An "embolus" (plural, "emboli") is a foreign body which may be in any part of the blood stream, and it may consist of gases, pieces of tissue, bacteria, etc. The term, "aeroembolism", was first used by Major Armstrong of the U.S. Army Medical Research Laboratory at Wright Field to describe the presence of air bubbles in the blood, These bubbles are composed largely of nitrogen and in part of oxygen, carbon dioxide and water vapor; each being present in proportion to the partial pressures of those gases.

B. Mechanism of:

1. Atmospheric pressure change.
Gases are present in the body in proportion to their pressure in the alveoli of the lungs, and at sea level the composition of alveolar air is as follows: Nitrogen, about 79%; oxygen, about 15.5%; and carbon dioxide, about 5.5%. The alveolar carbon dioxide pressure, because it is formed in the body and acts as the regulator of respiration, remains relatively constant at approximately 40 mm. Hg. regardless of the altitude. The partial pressure of oxygen decreases with altitude unless artificially maintained at the normal level of 100 mm. by the administration of additional oxygen. Nitrogen makes up the balance of the percentage and partial pressure of gases in the lungs.

2. Role of nitrogen.
At sea level, the partial pressure of alveolar nitrogen is 79 per cent of the barometric pressure less water vapor. That is, $0.79 \times (760 - 47)$, or 0.79×713, which is 563 mm. Hg. As the total barometric pressure is decreased by altitude, the partial pressure of nitrogen like that of oxygen is decreased proportionately. Also if 100% oxygen is inhaled, the amount of nitrogen in the lungs rapidly decreases; this will permit the gradual elimination of nitrogen from the body as fast as the blood can pick it up from the tissues and carry it to the lungs for elimination because gases, like water, "run down hill" from a higher to a lower pressure.

The procedure of nitrogen elimination from the body can therefore be hastened before ascending to high altitudes by the breathing of pure oxygen, and elimination is even more rapid if oxygen inhalation is accompanied by exercise. Since nitrogen is the principle factor in the formation of bubbles, we decrease this factor by getting rid of much of the nitrogen gas dissolved in the body. If from one-half to two-thirds of the nitrogen can be eliminated, the danger of aero-emphysema or aeroembolism is much decreased.

[illegible] Foreign body which may be in any part [illegible]

1. Atmospheric pressure changes.

[illegible] in proportion to their pressure in the alveoli of the [illegible] of [illegible] oxygen [illegible] and nitrogen [illegible] partial pressures [illegible] a normal level of [illegible] balance of [illegible] pressures and partial pressures of gases [illegible]

2. [illegible]

[illegible] partial pressure of alveolar water vapor is 75 per cent of [illegible] water vapor [illegible]

[illegible]

3. "Soda pop" illustrations.

The principle underlying bubble formation is easily understood if we recall that "soda pop" is bottled under increased pressure, and when the bottle cap is removed gas bubbles are liberated because the contents of the bottle are then exposed to a lower atmospheric pressure than the pressure at which the bottle was capped. Similarly, the gases in our body are liberated if the atmospheric pressure is decreased. When the air in the environment is decreased the whole body comes into a new gaseous equilibrium. According to Dalton's law, gases are soluble in fluids according to their partial pressures. The tissues which contain a large proportion of fat will contain more nitrogen in solution than the blood because fat dissolves more nitrogen than water or blood; therefore, fatty tissues will give up their dissolved nitrogen much more slowly than non-fatty tissues. In this connection it is necessary to remember that nerve and brain tissue contain a high proportion of fatty material.

4. Physiological changes (similar to "diver's bends").

Aero-emphysema with aeroembolism is similar to "caisson's disease" or the "bends" which develops is caisson workers and in divers during ascent from deep diving. However, the danger for divers is greater than in aviation because the actual mass of gas, or in other words, the actual number of molecules of gas in the bodies of these caisson workers is greater and they often endure a greater percentage change in atmospheric pressure. However, even with the same percentage change, that is, reducing the diver's atmospheric pressure from five atmospheres to one atmosphere and reducing the flyer's atmospheric pressure from one atmosphere to one-fifth atmosphere (ground level to 35,000 feet) the symptoms produced in the case of the diver will be more serious for reasons explained by Piccard.

In summarizing, aero-emphysema with aeroembolism is due to the fact that atmospheric gases, largely nitrogen, are dissolved in the body at ground level pressure and exist in a supersaturated state at the decreased pressures of high altitudes; thus forming bubbles just as a bottle of "soda pop" does when the cap is removed.

C. Symptoms.

1. Factors in production.

The danger of bubble formation under 30,000 feet altitude is comparatively slight, even though bubblesmicroscopic in size may actually begin to form as low as 12,000 feet. Rapidity of ascent, altitude reached, length of time of exposure to that altitude, and individual susceptibility are the determing factors in the nitrogen bubble production and associated symptoms. Modern day airplanes and modern warfare enable and require rapid climbs to very high altitudes, about 6 to 8 miles. It is here that the greatest danger of aeroembolism exists, especially if prolonged flights are made at these altitudes.

2. Symptoms experienced (subjective - roughly in order of occurence).

All or part of the following symptoms may be noted roughly in the order mentioned: smarting and scratchy sensation of the eyelids; a crawling sensation over the skin; pains in the hands, feet, legs and arms, especially around the joints or along the nerve trunk; giddiness, dizziness, or deafness (from bubbles in the inner ear); paralysis, usually in the legs which may appear suddenly and vary from weakness to complete loss of motion. In extreme cases, unconsciousness may set in with spontaneous defecation and urination. A pilot might occasionally regain consciousness by the time he had fallen to 8,000 to 12,000 feet.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

3. Prophylactic measures: preliminary decompression (denitrogenization) with special equipment.

Adequate protection may be had by "preliminary decompression" or "denitrogenization." This is accomplished by having the pilot and crew breathe pure oxygen while exercising, with vigorous movements of the legs to simulate a walk of two and one-half to three miles per hour together with a comparable movement of the arms. Massage of the abdomen helps to clear out the intestinal gases and there should be no hesitation about passing gas both "up and down." A treadmill, stationary bicycle, or "standing running" exercise may be used to increase the circulation of the blood. In addition, the mask and bag set up for this purpose must be properly constructed so that nothing but oxygen and a small amount of the carbon dioxide that will accumulate in a 4 or 5 liter reservoir rebreathing bag is breathed (no air should leak in). The carbon dioxide also increases the circulation rate in non-exercising parts of the body like the spinal cord and brain. However, care should be taken not to rebreathe enough so that the accumulation of carbon dioxide makes the subject uncomfortable. The amount of carbon dioxide is regulated by changing the oxygen flow and also by emptying the reservoir bag more frequently.

The breathing of oxygen combined with exercise enables the body to rid itself of one-half to two-thirds of the total gaseous nitrogen in the body. Following the exercise the aviator should sit down and rest until he has regained his breath. The oxygen is breathed also while going to the plane and during flight. This procedure when properly carried out will protect against a climb of a mile a minute to altitudes corresponding to 40,000 or even 42,000 feet.

Not only low pressure chamber experiments but also experience in actual flights show that without preliminary denitrogenization very few symptoms occur under 30,000 feet regardless of the rate of climb except in very susceptible individuals. However, above this altitude even rates of climb of 2,000 feet per minute or less may produce symptoms which increase in intensity after remaining more than 10 to 15 minutes above 30,000 or 35,000 feet.

From fifteen to twenty per cent of any advanced training group will have bends at 35,000 feet sufficient to force them to a lower altitude within three hours. Rapid treatment may be had by rapid descent to lower altitudes. Descent should be started immediately once severe symptoms are noted, but mild symptoms should cause no great concern if the aviator is at least partially denitrogenized. Severe symptoms usually disappear with descent of 5,000 to 10,000 feet, and after a few moments there, one may climb again but should be extremely cautious, especially if not decompressed.

VIII. Effects of Heat and Cold.

A. Effect of cold on body - mechanism for maintaining body temperature.

Before considering temperature changes in the atmosphere let us first consider the temperature and temperature regulating mechanism of our own bodies. Our normal body temperature is 37 degrees C. or 98.6 F. This may vary by ± 1.5 degrees F. and still be considered normal.

The metabolic rate is the rate of heat production in the body. It is dependent on numerous factors which we will not take up in detail. The metabolic rate is determined in the laboratory by measuring the amount of oxygen used by the body within a given time, i.e., rate of oxygen consumption. Work or exercise raises it, as does shivering which is a strenuous form of exercise. Shivering may raise the metabolic rate to four or five times what it is at rest and thus compensate for loss of heat. The ingestion of food requires energy for digestion and assimilation, and this raises the metabolic rate. We are all familiar with the fact that food or drink much warmer or colder than the body temperature will change the body temperature. The thing to keep uppermost in our minds, however, is that increased metabolism requires an increase of oxygen supply. Thus, in freezing weather our bodies strive to furnish us sufficient heat by increasing our metabolic rate. This calls for a greater supply of oxygen since metabolism is primarily a process of combustion or oxidation, that is, food is burned up in the body as coal is in the furnace. In addition, during cold weather, the heat regulating center tends to prevent loss of body heat by decreasing the amount of perspiration and by decreasing the amount of blood flowing to the skin.

Since the modern military pilot experiences rapid and great changes of altitude, he also experiences rapid and great changes of temperature. He should be fully aware of these changes and the danger involved, and most important, know how to protect himself against these temperature changes. Fortunately, most of our present day airmen are young, and young men possess rapid and more adequate responses to cold than do older men who are more sensitive to temperature.

B. Atmosphere.

In the atmosphere there is a gradual and fairly regular temperature drop (in summer) from an average temperature of 15° C. at sea level to about -50° C. at 11 kilometers after which it remains essentially constant. In winter the decrease in temperature reaches -55° C. at 10 kilometers (Figs. 17 and 18, "Physics of the Air," by W. J. Humphreys).

C. Effects of freezing on the body.

Mild chilling, "goose pimples," and shivering may follow in the named order in the early stages of freezing. Unless adequate protection against cold is available these symptoms become progressively more severe and finally stiffness of the extremities with numbness, poor coordination, poor judgment and a tendency to sleep occurs. In the later stages of freezing, as is well known, the unfortunate victim may experience no subjective symptoms and be totally unaware of his extreme danger; he becomes drowsy and wants to drop off to sleep - and may never awaken.

D. Protection against cold.

For preventing frost bite, cold cream, vaseline or other bland ointments smeared on the hands and face are excellent. Care should be taken when applying such greases to the hands that not enough is used to make the joystick, throttle, etc. so slippery that proper control of them would be difficult.

The principle means of combating cold temperatues is by means of proper clothing and by heated cabins. In combat it is essential that every plane crew member be as comfortable as possible - at least to such an extent that

The metabolic rate is the rate of heat production in the body. It is dependent on numerous factors which we will not take up in detail. The metabolic rate is determined, in the laboratory by measuring the amount of oxygen used by the body [illegible] Work or exercise raises it, and shivering which is a strenuous form of exercise. Shivering may raise the metabolic rate to four or five times what it is at rest, and thus compensate for loss of heat. The ingestion of food also raises it for digestion and assimilation, and this raises the metabolic [illegible] familiar with the [illegible] that [illegible] or drink such as [illegible] [illegible] the body temperature will change the body temperature [illegible] [illegible] is very important [illegible] however, is that increased metabolism [illegible] an increased oxygen supply. Thus, in freezing weather our bodies [illegible] as [illegible] by increasing our metabolic rate. This calls for a greater supply of oxygen since metabolism is primarily a process of combustion or oxidation; that is, food is burned up in the body as coal in the furnace. In addition, during cold weather, the heat regulating center tends to prevent loss of body heat by decreasing the amount of perspiration and by decreasing the amount of blood flowing to the skin.

Since the modern military pilot experiences rapid and great changes of altitude, he also experiences rapid and great changes of temperature. He should be fully aware of these changes and the [illegible] involved, and, most important, know how to protect himself against these temperature changes. Fortunately, most of our present day airmen are young, and young men possess better and more adequate [illegible] to [illegible] than do older men who are more susceptible to [illegible].

1. [illegible]

In the atmosphere there is a gradual and fairly regular temperature drop from [illegible] average temperature of 15° C. at sea level to about -55° C. at 11 kilometers after which it remains essentially constant. In winter the average in temperature reaches -55° C. at 10 kilometers (Fig. 17 and 18, [illegible] by W. J. Humphreys).

2. [illegible]

Mild chilling, "goose pimples," or shivering may follow in the manner [illegible] in the early stages of freezing. Unless adequate protection against cold is [illegible] [illegible] of the extremities with numbness, poor coordination, poor judgment and a tendency to sleep occurs. In the later stages of freezing, as is well known, the unfortunate victim may experience no subjective symptoms and be totally unaware of his extreme danger. He becomes drowsy and wants to drop off to sleep - and may never awaken.

3. [illegible]

For preventing frost bite, cold cream, vaseline or other bland ointments smeared on the hands and face are excellent. Care should be taken when [illegible] [illegible] rubbing, etc. [illegible] proper control of them would be difficult.

The [illegible] means of combating cold temperatures is by means of proper [illegible] and [illegible] cabins. In combat it is essential that every plane [illegible] be as comfortable as possible - at least to such an extent that

he is not hindered in carrying out his duties efficiently. This not only means that each must be comfortably warm, but he must also not be handicapped by clothes that are too bulky. Two thin garments afford better protection against cold than does one thick garment, even though the total thickness of the two is less than that of the one thick garment. This is because of the insulating layer of air between the two garments which serves to prevent excess loss of heat from the body surface as well as serving to insulate against the outside cold. Garments should not fit too tightly; however, they should be snug at the wrists, collar and ankles to prevent outside air from blowing in.

The fur-lined clothing which is now used is rather bulky. Electrically heated clothing now in use is far less bulky and permits each individual to adjust the heat as he desires. The disadvantages of this latter type are that the source of heat may fail, it won't be available if the ship is forcibly abandoned, and it requires a very large amount of electrical energy. Electrically heated clothing is only efficient when well insulated on the outside by properly constructed clothing. Progress is now being made in incorporating the best features of both types of clothing for the future.

Two principal methods have been used to heat the cabins of planes. The first is not desirable, is dangerous, and practically obsolete now. This is the collection of heated air from around the exhaust and conducting it to the cabin. This is a very dangerous method as a small leakage of carbon monoxide could result in disaster to the plane's occupants in a very short time. The second type is more satisfactory, and utilizes the exhaust to heat a small tank of hot water which in turn gives off steam for circulation within the plane. This is by far the safer and more desirable method.

IX. Effects of Speed and Centrifugal Force.

A. Speed.

A speed in excess of 425 miles per hour has been attained. In straight-away flying probably speed in flight has no other effect than that of a terrific blast of air. While traveling at such a tremendous rate of speed the flyer does not dare expose parts of his body to such terrific pressure. If he held out an arm it would probably be broken, or if he stood up in his cockput his head would probably be snapped backward with such force that his neck would be broken.

B. Centrifugal force and speed.

The real danger in tremendous speed, however, is during banks and turns, and is due to centrifugal force. As the flier makes a bank and turns abruptly from his original line of flight the "pull" of centrifugal force acts in the direction of the radius of the turn, that is, away from his head and toward his feet. The result is that the blood is literally thrown away from his brain, causing cerebral anemia or a faint. The underlying principle of the blackout (on inside loop) is that 1 pint of blood instead of weighing 1 pound as is normal under the influence of normal gravity (1 g), weighs five, six or seven times as much when the force of gravity becomes equivalent to five, six or seven g.

The heart cannot pump this heavy blood up into the head. As a matter of fact, it "falls" down into the lower belly and legs. Note that the direction of blood flow is toward the pilot's head until he starts to pull out of his dive. At this latter period he meets centrifugal force which reverses the direction of the blood flow. Very shortly afterward he begins to go into a blackout, with progressive decrease in the blood supply and therefore, of the oxygen supply to the brain. Note that the blackout, which is experienced is a darkening of the fields of vision. The complete blackout occurs not as soon as the individual begins to come out of the dive but at a later period. As the plane levels out, normal vision is restored. The more rapid and sharp "pull outs" cause more rapid and more complete blackouts. This phenomenon is often noticed by pilots flying in races, and also in pulling out of fast dives abruptly. The tendency toward fainting or "passing out" on turns and pulling out of dives apparently varies greatly with individuals. Some state emphatically that they have never experienced such a sensation, possibly because the aviator failed to appreciate that he had for a few seconds become unconscious. It seems to vary at times in one individual, and possibly depends to some extent upon his general physical condition. One pilot described the sensation that he experienced in pulling out of a dive as follows: "Suddenly spots appeared before my eyes and then everything went black for an instant, probably one or two seconds, judging from the altitude I had gained.

There is also a condition we call a "redout" which is just the opposite to a blackout. Redouts are experienced in outside loops where centrifugal force acts to throw the blood flow toward the head. This increases the blood volume and pressure in the heat to such an extent that the small blood vessels of the eyes are overfilled with red blood and may even rupture. The individual in which this occurs looks through this blood and receives the same visual effect as looking through a red film - in this instance a film of blood. Individuals with high blood pressure may have redouts of such severity that they may be accompanied by rupture of blood vessels of the brain - similar to an apoplectic stroke, and very dangerous.

Another method of preventing blackouts, is, by crouching forward in the cockpit. When a pilot is sitting in an erect position, the distance from his heart to his brain is greater than when he is crouching. The completely prone or supine position is the best position for prevention of blackout since the heart and head are at the same level; however, such positions are not practical. The crouch position is practical and may prevent some blackouts or at least diminish the severity of blackouts.

An abdominal pressure belt and later "suits" have been used for prevention of blackouts, but these contrivances have not yet been found entirely satisfactory. The pressure belt or suit is sometimes automatically inflated as one "pulls out" and by exerting pressure against the blood vessels of the legs and abdomen it acts to lessen their capacity to collect blood from the head.

[illegible] heart cannot pump this heavy blood up into the head. As a matter of fact, [illegible] "[illegible]" [illegible] the lower body and legs. Note that the direction of [illegible] is toward the pilot's head until he starts to pull out of his dive. [illegible] this latter period he meets centrifugal force which [illegible] the [illegible] of the blood flow. Very shortly afterward he begins to go into a [illegible], [illegible] increase in the blood supply and therefore, of the [illegible], [illegible] to the brain. Note that the blackout, which is experienced [illegible] a [illegible] of the [illegible] of vision. The complete blackout occurs [illegible] as the individual begins to come out of the dive but at a later [illegible]. [illegible] the plane levels out, normal vision is restored. The [illegible] [illegible] and strong "pull outs" cause more [illegible] and more complete blackouts. [illegible] is [illegible] by pilots flying in [illegible], and [illegible] in pulling out of fast dives [illegible]. The tendency toward [illegible] or "passing out" on [illegible] in pulling out of dives [illegible] varies greatly with individuals. Some [illegible] that they have never experienced such a sensation, possibly [illegible] they [illegible] that [illegible] for a [illegible] [illegible]. It seems to vary at times in one individual, and possibly [illegible] [illegible] all general [illegible]. One pilot [illegible] [illegible] that he experienced in pulling out of a dive as follows: "Suddenly [illegible] appeared before my eyes and then everything went black for an instant, [illegible] one or two seconds, judging from the altitude I had [illegible]."

[illegible] is also a condition we call a "redout" which is just the opposite to [illegible]. It [illegible] are experienced in [illegible] where centrifugal force [illegible] the blood [illegible] toward the head. This increases the blood volume [illegible] pressure in the head to such an extent that the small blood vessels of the [illegible] are overfilled with red blood and may even rupture. The individual [illegible] [illegible] looks through this blood and receives the same visual effect [illegible] looking through a red film - in this instance a film of blood. Individuals [illegible] blood pressure may have redouts of such severity that they may be [illegible] by rupture of blood vessels of the brain - similar to an apoplectic [illegible], and very dangerous.

[illegible] method of preventing blackouts, is by [illegible] forward in the [illegible]. When a pilot is sitting in an erect position, the distance from his [illegible] to his brain is greater than when he is [illegible]. The completely [illegible] position is the best position for prevention of blackout [illegible]. The [illegible] and head are at the same level; however, such positions are not practical. [illegible] position is practical and may prevent some blackouts or at least [illegible] the severity of blackouts.

[illegible] pressure [illegible] have been used for prevention of blackouts, but [illegible] [illegible] [illegible]. [illegible] automatically inflated as [illegible] [illegible] pressure against the blood vessels of the legs and [illegible] their capacity to [illegible] blood from the head.

X. Barometric Pressure Changes and the Ear.

A. Ear anatomy.

As mentioned previously, ascent to high altitudes (decreasing barometric pressure) affects the ears, sinuses and intestines. We shall first consider the ear. If you will notice the chart of the anatomy of the ear, you will see the external auditory canal, the tympanic membrane or ear drum, and the eustachian tube. (Instructor uses pointer on anatomical chart.) The external auditory canal is what the physician peeks into with an otoscope to get a good view of the ear drum (tympanic membrane). The ear drum may be compared to a sheet of thin rubber in its ability to "pooch out" (bulge) and "pooch in" (retract), especially if that sheet rubber is thought of as covering one end of a tube. By blowing into the open end of the tube, the rubber sheet will bulge outward, and if we suck in on the open end, we create a negative pressure and cause the rubber sheet to retract. The ear drum will bulge out if the gas pressure in the middle ear is greater than that outside; on the other hand the pressure in the middle ear is less than that in the atmosphere and the ear drum bulges inward (retraction).

The principle action of the eustachian tube is to drain and ventilate or equalize the air pressure of the middle ear and the atmospheric pressure. The eustachian tube is opened by its dilato r muscles in the nasopharynx; opening, it equalizes any pressure differential existing between the middle ear and the atmosphere. The dilator muscles act to open the eustachian tube during swallowing, yawning, and other physiologic acts.

B. Ascent

If we begin at sea level and ascend without ventilating the middle ear by opening the eustachian tube, there is pain with bulging outwards of the ear drum, the degree of bulging depending on the altitude attained. As we ascend, the pressure in the non-ventilated middle ear remains the same as it was at sea level, while the atmospheric pressure decreases. Hence the greater pressure in the middle ear pushes the tympanic membrane outward toward the lesser pressure of the atmosphere. If sufficient altitude is reached, the bulging may be great enough to burst the tympanic membrane. Similarly, if we assume the middle ear and atmospheric pressure have been equalized at a high altitude and then begin to descend without ventilating the middle ear, we have a reversal of the process, i.e., the tympanic membrane is pushed inward.

C. Descent.

The pain and other symptoms are more prominent on descent than on ascent. If there is ventilation of the middle ear during descent, then its pressure remains stationary with development of a relative negative pressure, while the atmospheric pressure progressively becomes greater and forces the tympanic membrane in toward the middle ear, resulting in a retracted ear drum.

In this instance, the pressure within the middle ear is less than that of the atmosphere. Such a negative pressure of 80 to 90 mm, of mercury within the middle ear makes it impossible for the eustachian muscles to overcome the negative pressure which holds the eustachian tube tightly collapsed. It then becomes necessary to decrease the middle ear pressure to about 70 mm. of mercury of negative pressure or less before the eustachian tubes can again

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

be voluntarily opened. This necessitates ascending again to an altitude where the middle ear and atmospheric pressure are more nearly equalized.

D. Aero-Otitis Media ("Ear Block," "Aviation Ear").

1. Definition.

"Aero-otitis media" or "aviation ear" is a term coined to refer to the results due to the lack of ventilation of the middle ear during changes of atmospheric pressure to the extent that the tympanic membrane and cavity are injured.

2. Cause of improper middle ear ventilation.

The two principal causes of improper middle ear ventilation are; first, a failure to open the eustachian tube voluntarily when necessary; second, the inability to open it and this is much more prevalent than is generally recognized. Frequent causes of inability to open the eustachian tube are: ignorance of the physiologic mechanisms, obstructions of the nose, sinusitis, tonsillitis, tumors or growths of the nose, mouth, etc. On the other hand, experience and training greatly increase one's ability to open the eustachian tube. Every flight surgeon has had innumerable experiences with the cadet who thought he should certainly not be grounded because he had a sore throat. The flight surgeon realized only too well the danger of a sore throat. The inflammation of the throat often involves the opening of the eustachian tube and causes a partial or complete closure of the tube so that proper ventilation of the middle ear is not possible and woe betides the flier who flies with a sore throat and then after landing "blows his ears out" by closing the nose and mouth, for this usually forces germs from the infected throat into the eustachian tube and middle ear with serious complications resulting.

3. Symptoms.

Let us briefly consider the symptoms of aero-otitis media which may be brought on by ascent or descent with improper ear ventilation. One of the earliest symptoms is a feeling of fullness in the middle ear. In chronic cases due to repeated mild injury to the ears there is a "full and stuffy" feeling in the ears and difficulty in "clearing" them. Varying degrees of loss of hearing may occur. With rupture of an ear drum pain may become unbearable. The subject feels "as though hit along the side of the head with a plank" and there is a sharp pierc ing pain on the affected side with marked dizziness and nausea. Collapse or shock may follow.

4. Prophylaxis.

Again, the simplest maneuver to open the eustachian tube is to swallow. Yawning, singing, shouting, etc. may also accomplish it. The sucking of candied mints while flying causes frequent swallowing and is probably better than chewing gum, as the latter soon loses its flavor. The average person swallows involuntarily about once every 60-75 seconds so that rates of climb of 500 feet per minute or more result in progressively greater degrees of discomfort if no effort is made to ventilate the middle ear. Sleeping and unconscious individuals present a serious problem. Commercial airlines have an allowable rate of ascent and descent of 200 to 300 feet per minute; however, military flying requ ires more rapid rates of ascent and descent with, of course, greater care regarding the ears.

[illegible]

[illegible]

[illegible]

[illegible]

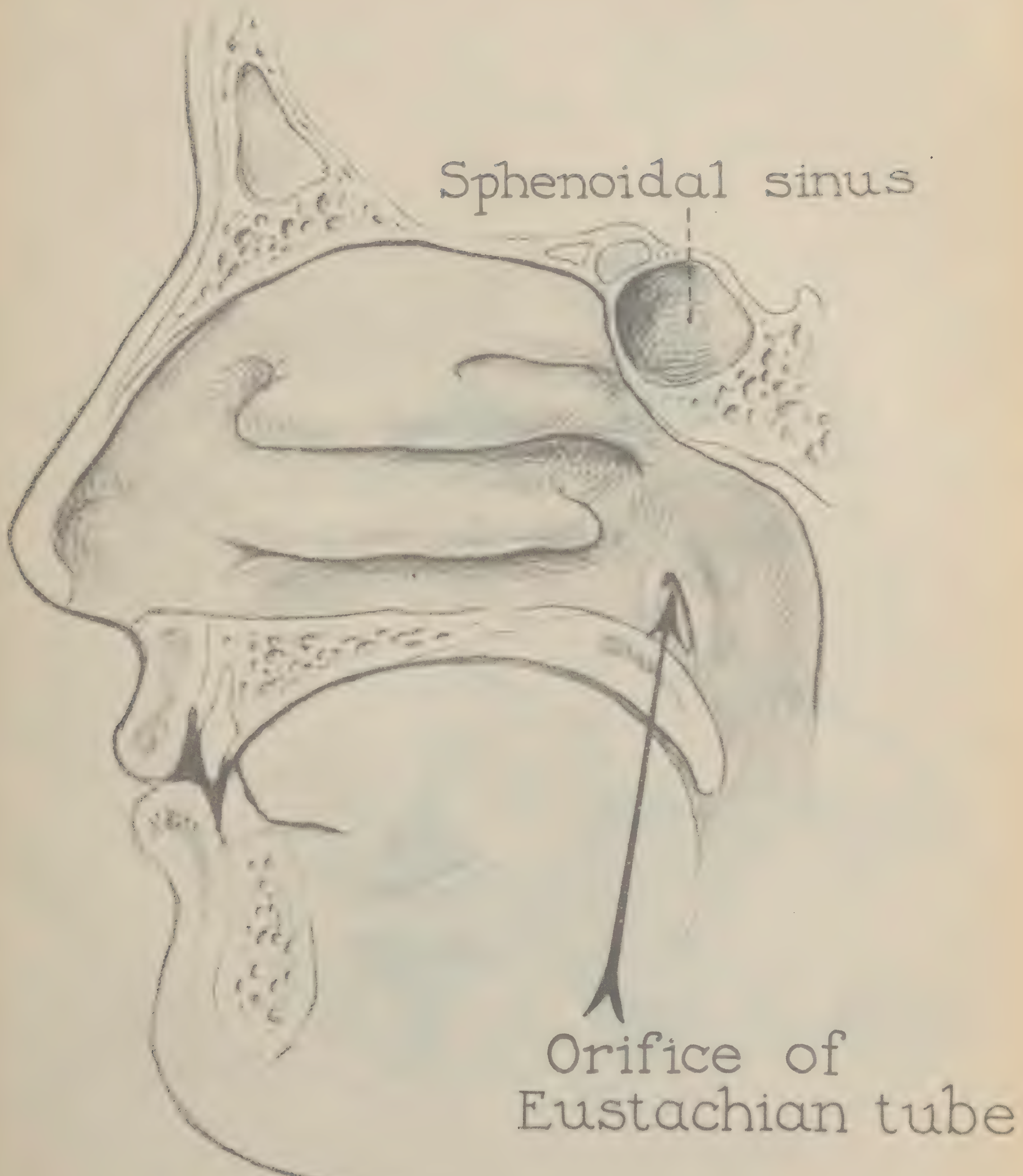
[illegible]

[illegible]

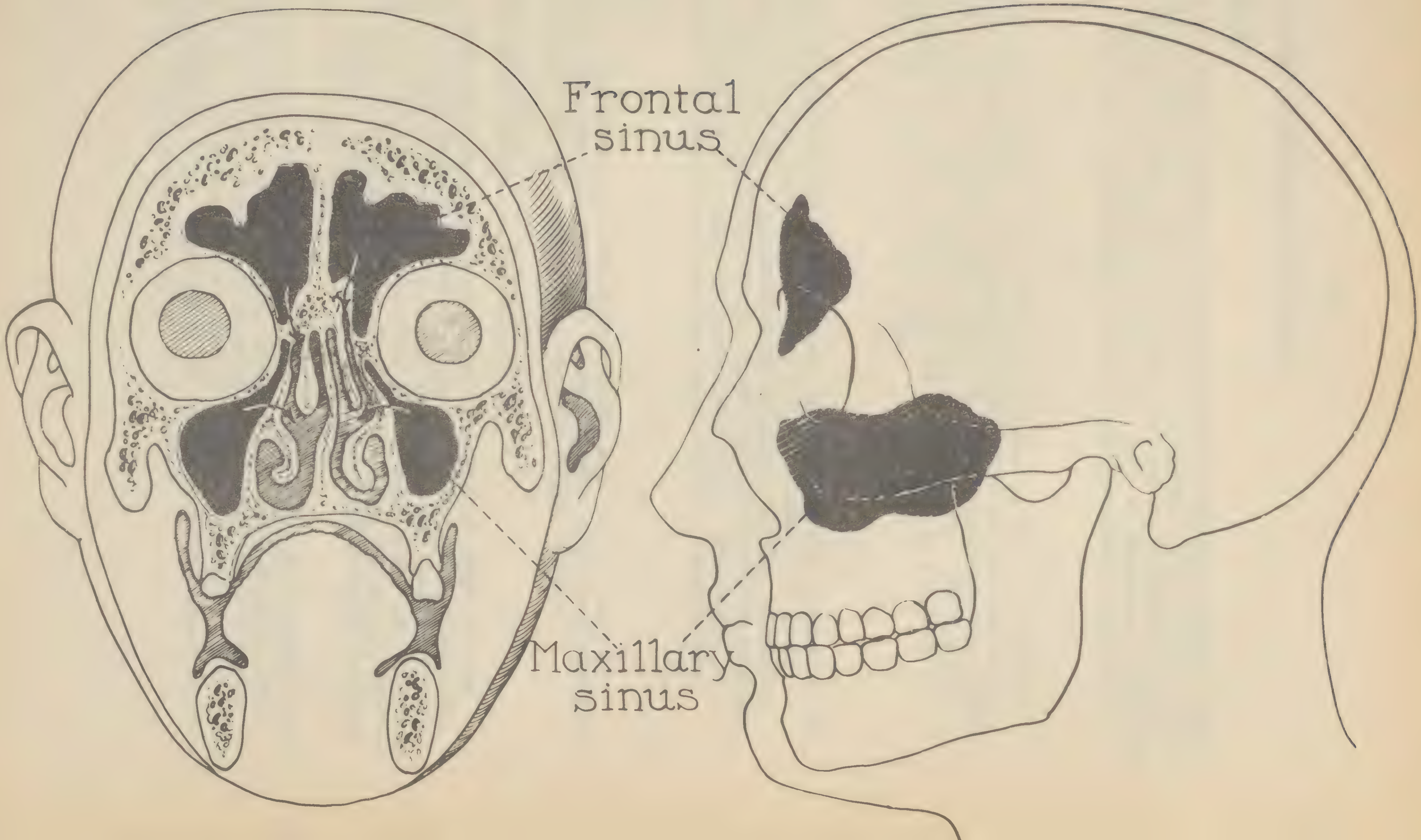
[illegible]

Diagrammatic sketch of the external, middle and internal ear and the eustachian tube.

SAGITAL SECTION
TO SHOW
ORIFICE OF EUSTACHIAN TUBE



AND THEIR CONNECTION TO THE NASAL CAVITY



XI. Barometric Pressure Changes and the Sinuses.

A. Brief anatomy.

The nasal accessory sinuses are also affected by barometric changes. These are located in the hollowed out spaces of the face bones. Two of these sinuses are located here in the cheek, two are located here in the forehead, and two of them are located in the bones just back of the root of the nose. Ordinarily air passes in and out of these sinuses through small openings in the nose.

B. Ascent.

During ascent and descent to and from high altitudes, the air in these sinuses changes pressure with the atmospheric pressure, as does the air in the middle ears, and similarly, should there be an obstruction to the sinuses, the air cannot escape readily and ill effects are produced. For instance, in ascent the expanded air in the sinuses cannot escape, and by building up pressure within the sinuses it causes pain.

C. Descent.

The reverse of this is true during descent when a vacuum is created in the sinuses and air from the atmosphere cannot enter the sinuses. Pain is produced here also and may be accompanied by headache, eyeache, dizziness, and nausea. Pilots with sinus infection, obstruction of the sinus openings, or head colds should not fly until the condition has been corrected. To fly may aggravate the condition and perhaps cause serious complications.

D. Treatment.

A benzedrine inhaler sniffed just before flying may help at times but warning is given that the inhaler should be used no more often that once every hour and should only be used after consulting your flight surgeon.

XII. Barometric Pressure Changes and Intestinal Gases.

Expansion of abdominal gases may cause marked discomfort in high altitude flying unless properly combatted. Gases expand with decrease in atmospheric pressure. As an example, a toy balloon when taken from sea level to 35,000 feet will increase its volume more than four times. Similarly, the intestinal gases will do likewise with production of marked abdominal distension and discomfort. In severe cases marked abdominal cramps, difficulty in breathing and interference with the heart's action may result.

Anyone comtemplating a high altitude flight should avoid gas forming foods and drinks such as beans, cabbage, peas, beer and carbonated drinks. Avoid constipation. The taking of charcoal by mouth helps absorb some of these gases. Once distension and discomfort are experienced, relief may be obtained by either descending to lower altitudes or by massaging the abdomen with the hand followed by belching and the passage of flatus.

[illegible] Changes and Ill Effects

A. [illegible]

The nasal accessory sinuses are also affected by barometric changes. These are located in the hollowed out spaces of the face bones. [illegible] [illegible] [illegible]

B. [illegible]

[illegible] pressure and descent [illegible] from high altitudes, [illegible] [illegible] pressure [illegible] [illegible] [illegible] ill effects are produced. [illegible] result, [illegible] air in the sinuses cannot escape, and by building up pressure [illegible] causes it intense pain.

C. [illegible]

The pressure [illegible] having [illegible] when a [illegible] is [illegible] [illegible] cannot [illegible] the [illegible] [illegible] [illegible] complications.

D. [illegible]

A [illegible] but before flying may help at times but [illegible] should [illegible] [illegible] your [illegible].

[illegible] and [illegible]

[illegible] of physical [illegible] [illegible]

[illegible] should [illegible]

XIII. Hyperventilation.

A. Definition.

There is one more important thing to consider and that is hyperventilation. "Hyper," meaning very much or too much, and "ventilation" meaning just that. In hyperventilation there is more breathing, or ventilation, than the body requires.

B. Symptoms.

The symptoms of hyperventilation may be serious, and are: dizziness, a rapid pulse, marked perspiration, clamminess, visual disturbances, errors of judgment, muscular spasms and unconsciousness. Hyperventilation usually occurs insiduously, coming on without the victim being aware of it unless he is familiar with the signs and symptoms. Anxiety such as occurs during combat, fear, panic or hysteria often lead to hyperventilation.

C. Treatment.

The treatment of hyperventilation, fortunately, is quite simple, just hold the breath for about one minute in order to build up the carbon dioxide content of the blood which was diminished by hyperventilating.

D. Demonstration.

We shall now have six members of the class hyperventilate under my direction for 2½ minutes and at the conclusion I shall have them describe to the class the symptoms they have experienced. (Demonstration by instructor and six students.)

SUGGESTIVE
OUTLINE FOR LOW PRESSURE CHAMBER "RUN"
FOR AIR FORCE AND MEDICAL OFFICERS.

Operating Personnel: Two medical officers, one trained chamber operator, one mechanic.

Time Required: Approximately 1½ hours.

1. Review again the physiology and symptoms of aeroembolism and effects of denitrogenization preliminary to rapid high altitude ascents.
2. Inquire as to whether any students have colds, ear or sinus trouble. Leave these affected students out of chamber ascent.
3. Explain that group preliminary denitrogenization will be followed by chamber
3. ascent to 40,000 feet.
4. Demonstrate exercise. Explain and demonstrate that rate of 3 miles per hour for 30 minutes will be used, and while exercising the student must keep arms in motion using weights. He must deflate rebreather bag every 5 minutes with hands to prevent uncomfortable CO_2 accumulation.
5. Demonstrate oxygen supply system for denitrogenization and in chamber.
6. Fit denitrogenization masks to students and start exercise.
7. Check students for correct decompression procedure with assistants. Be certain each has 14 to 20 liters oxygen flow per minute depending on size.
8. Allow students to rest in chairs for 5 to 10 minutes after exercise, continuing oxygen inhalation.
9. Transfer students to chamber in pairs. Have each take large breath of oxygen, disconnect him from oxygen tank, shut off tank, then seat student in chamber and connect chamber oxygen supply.
10. Close chamber door after all students are seated. Check oxygen flow and mask of each student.
11. Medical officer has microphone connected to public speaker system and also connected by earphones to operator outside of chamber.
12. Ascent made to 5000 feet. Altitude announced. Warn students that a descent of 1500 feet in one minute is to be made and students are to swallow and care for ears and sinuses.
13. Descend to 3000 feet at rate of 1500 feet per minute. Level off if any student has marked symptoms, then descend to sea level and remove these complaining students from chamber and send them to E. E. N. T. Department for examination.
14. Announce ascent to be made to 30,000 feet at 3000 feet per minute for first 10,000 feet and 6000 feet per minute for last 20,000 feet. Ask students not to hesitate in informing you of any difficulty they may seem to be having, i.e., sinus or ear trouble, abdominal cramps, soreness in joints, crawling sensation of skin, etc. Level off or drop 5000 to 10,000 feet for 10 minutes; if definite symptoms noted then, proceed with care. Observer constantly watches for hyperventilation
15. Signal ascent. Constantly observe students, check their equipment and review orally to them the symptoms of aeroembolism, and remind them again of intestinal gas expansion. Have students with mild abdominal discomfort massage abdomen, belch and pass flatus.
16. Stop at 30,000 feet for 5 to 10 minutes. Have students note their own and neighbor's fingernail color, and skin color. Have them note clearness of vision and mind, pulse rates, etc. Ask them to note same at higher altitudes.
17. Announce ascent to be made to 40,000 feet. Check all equipment.
18. Signal ascent. Ascend to 40,000 feet. Remain there 5 minutes. Keep emergency oxygen supply masks handy. Closely observe all students. Return to 30,000 feet for 5 minutes, then return to 40,000 feet for as long as time permits. (Alteration of altitude is beneficial physically and psychologically).

[illegible]

Reading Assignment: [illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
9. [illegible]
10. [illegible]
11. [illegible]
12. [illegible]
13. [illegible]
14. [illegible]
15. [illegible]
16. [illegible]
17. [illegible]
18. [illegible]

19. Have three students lift 10 pound weight from lap vertically above head (4 feet) about 15 times in 30 seconds. Have other students note any cyanosis or other symptoms that may result. This amount of work is equivalent to 1200 feet pounds per minute.
20. Announce descent.
21. Signal descent. Should any student develop <u>dangerous</u> symptoms at high atltitudes, use air lock, if available.
22. Descend at 4,000 to 5,000 feet per minute to 10 or 12,000 feet. Remove oxygen masks then descend at 1000 or 2000 feet per minute to ground level. Avoid sudden pressure drops near ground level.
23. Answer students' questions. Impress students with value and safety of preliminary decompression.
24. Record findings and impressions of each student.

RECOMMENDATIONS CONCERNING OPERATION OF
THE LOW PRESSURE CHAMBER AND LABORATORY

I. That two trained flight surgeons supervise the low pressure chamber and laboratory.

II. That each medical officer ascend in chamber above 30,000 feet no more often than every other day; lower ascents could be made daily.

III. That the duties of the medical officers be to:
- A. Supervise laboratory.
- B. Supervise low pressure chamber.
- C. Be available near chamber at all times while his fellow medical officer is in the chamber, and to help prepare and observe students for and during a "run."
- D. Keep a complete log of each run: names of students, instructors, times of reaching each 5000 foot altitude and any severe or serious reactions of students.
- E. Make recommendations and reports on students regularly.

IV. That two trained operators, preferably of one of the grades of sergeant, be used to control the chamber. Their duties would be to:
- A. Control chamber ascents and descents in the chamber on direction of the medical officers.
- B. Clean oxygen masks after each run.
- C. Be responsible for oxygen tanks and oxygen supply in tanks at all times.
- D. Supervise department sanitation.
- E. Care for equipment and run projector for any films shown.
- F. Care for log books and other laboratory data.
- G. Care for all material to be distributed to students, as printed tests, pencils, etc.

V. That a trained mechanic, preferably of one of the grades of sergeant, be available at all times. His duties would be to:
- A. Care for and maintain pumps and chamber.
- B. Routinely check and care for all equipment, especially oxygen connections.
- C. Assist chamber operator and medical officers when necessary.

VI. That the medical officers be permitted to do research work, especially "clinical" if they show ability, interest and desire and that under those conditions the seventh recommendation be followed.

VII. That two trained laboratory technicians be made available. They should be familiar with:
- A. Haldane gas analyses (alveolar and mask air analyses).
- B. Van Slyke analyses (blood gas analyses).
- C. Blood counts.
- D. Typewriting ability.

VIII. That moving picture films be used to supplement lectures and demonstrations. (Dr. W. M. Boothby of the Mayo Clinic has some excellent ones for teaching purposes and is producing more.)

IX. That chamber communication available be of the following types:
- A. One permitting the medical officer in the chamber to address students by loudspeaker and yet have connection with the outside operator by means of earphones on the medical officer. At times the operator may wish to convey a warning or personal message regarding students to the medical officer inside the chamber.
- B. One permitting the medical officer on the outside to lecture by loudspeaker system to the students on the inside of the chamber. This is important at 40,000 feet when the medical officer on the inside should do as little talking as possible.

X. That "standing running" exercises be used in producing preliminary decompression if treadmills or bicycles are not available. This would require no installation or expense. (Attention is called to the proper procedure for preliminary denitrogenization as presented in the "Outline for Low Pressure Chamber 'Run' for Air Force Medical Officers.")

[illegible]

I. [illegible]

II. That each medical officer ascend in chamber above 30,000 feet no more often than every other day; lower ascents could be made daily.

III. That the duties of the medical officers be to:

A. [illegible] laboratory.
B. [illegible] chamber.
C. be available [illegible] at all times while his fellow medical officer is in the chamber, and to help prepare and observe students for and during a "run."
D. Keep a complete log of each run: names of students, instructors, times of ascent, each [illegible] feet altitude and any severe or serious reactions of students.
E. [illegible]

IV. That two trained operators, preferably of one of the grades of sergeant, be used to control the chamber. Their duties would be to:

A. Control chamber ascents and descents in the chamber on direction of the medical officers.
B. Clean oxygen masks after each run.
C. Be responsible for oxygen tanks and [illegible]
D. [illegible]
E. Care for equipment and run projector for any films shown.
F. Care for log books and other laboratory data.
G. Care for all material to be distributed to students, as printed texts, pamphlets, etc.

V. That a trained mechanic, preferably of one of the grades of sergeant, be available at all times. His duties would be to:

A. [illegible] and maintain pumps and chamber.
B. Routinely check and care for all equipment, especially oxygen connections.
C. Assist chamber operator and medical officers when necessary.

VI. That the medical officers be permitted to do research work, especially "clinic" if they show ability, interest and desire and that under these conditions the research [illegible] be followed.

VII. That two trained laboratory technicians be made available. They should be trained in:

A. Routine gas analyses (alveolar and mask air analyses).
B. [illegible] (blood gas analyses).
C. [illegible]
D. [illegible]

VIII. That moving picture films be used to supplement lectures and demonstrations. ([illegible] of the [illegible] Clinic has some excellent ones for teaching purposes and is producing more.)

IX. That chamber communication available [illegible] of the following types:

A. One [illegible] the medical officer [illegible] chamber to address students by [illegible] and [illegible] have connection with the outside operator by means of [illegible] on the medical officer. At times the operator may wish to [illegible] a warning or general message regarding students to the medical officer inside the chamber.

B. [illegible], the medical officer on the outside to lecture by loudspeaker system to the students on the inside of the chamber. This is important at 40,000 feet when the medical officer on the inside should do as little talking as possible.

X. [illegible]